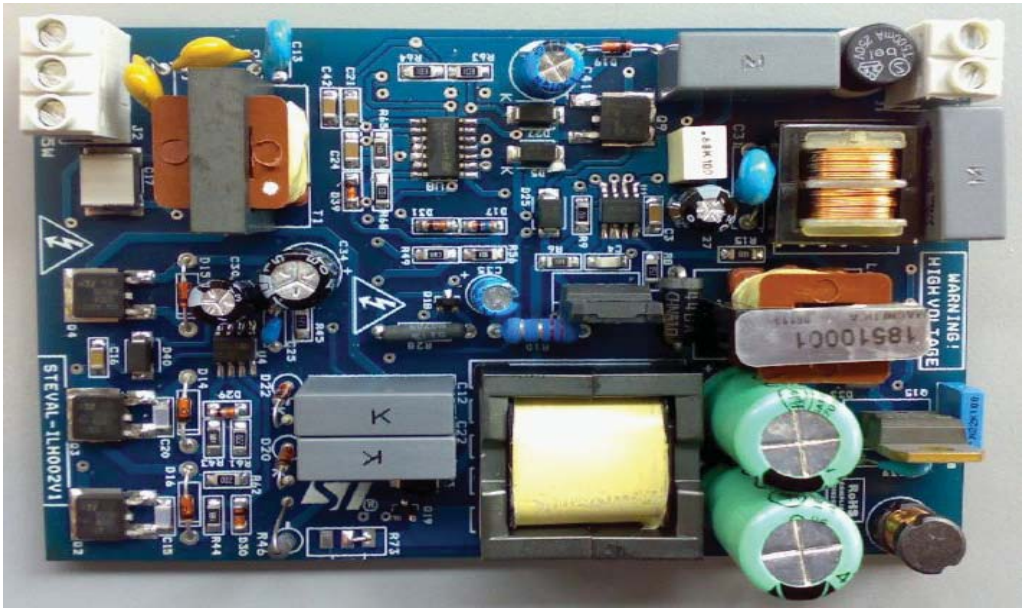
AN2952
Application note

35 W electronic ballast for HID lamps

Introduction

Low-power metal halide lamps are becoming popular as lighting sources in indoor environments like shopping centers or malls, serving as alternatives to more traditional halogen lamps, thanks to their intrinsic higher efficiency, longer lifetime and optimal color rendering. Until now, electronic circuits supplying HID lamps made use of microcontrollers and complicated topologies. Generally four power switches are used in full-bridge topology, two of which work at high frequency (80 kHz-100 kHz) in order to regulate the lamp current, while the other two work at low frequency (150 Hz-400 Hz). This application note describes an innovative analog solution for a complete ballast circuitry optimized to feed a 35 W high intensity discharge (HID) metal halide lamp (MHL), without making use of any microcontroller to regulate and control the lighting output. This circuitry is used on demonstration board STEVAL-ILH002V1 shown in figure 1. The lamps used for this design are a 35 W metal halide lamp CDM-T (Philips) and an HCI-T (Osram).

Figure 1. STEVAL-ILH002V1



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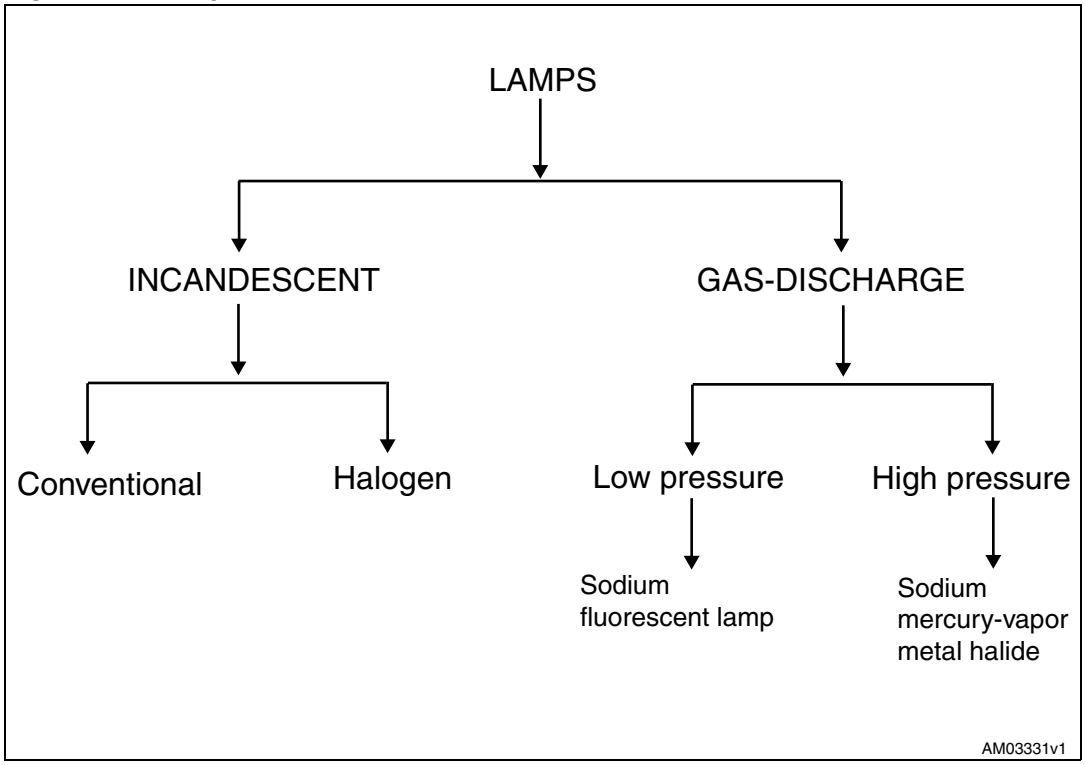
1 Lamp descpription

In the last year high-intensity discharge (HID) lamps have become attractive lighting sources for their luminous efficacy and their long life. In *Figure 2* the generic lamp families are illustrated.

Figure 2. Lamp families

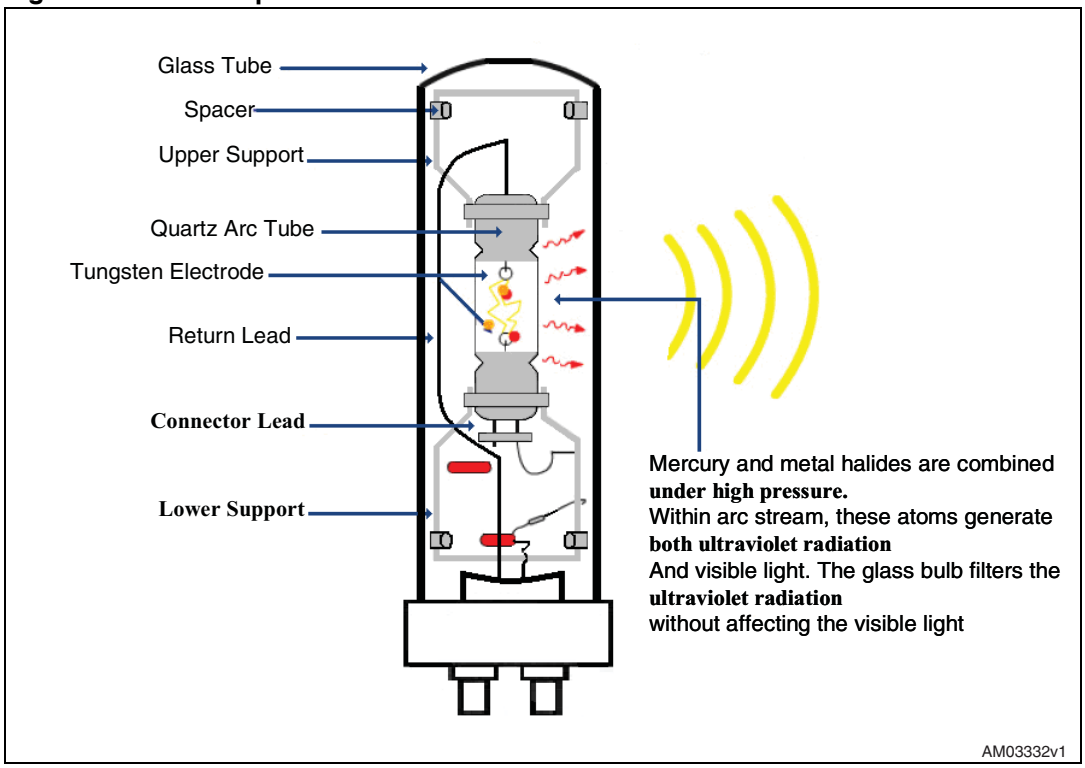


2 HID technology

Like fluorescent lamps, HID lamps require a ballast circuitry to properly supply the lamps themselves. Also the technology in high-intensity discharge lighting is in some ways similar to that of fluorescent lamps. An arc is established between two electrodes in a gas-filled tube which causes a metallic vapor to produce radiant energy. In fact when sufficient voltage is applied to the electrodes, an arc is formed between them. Electrons in the arc stream collide with atoms of vaporized metals, shifting the wavelength of this energy into the visible range, so light is produced without adding any phosphor coating in the inner side of the bulb. In addition, the length of the electrodes is only few inches and the gases in the tube are highly pressurized. The arc generates extremely high temperatures, causing the vaporization of metallic elements in the gas atmosphere and the release of massive amounts of visible radiant energy. There are three primary types of HID lamps: mercury vapor, sodium and metal halide. The names refer to the elements that are added to the gases in the arc stream which cause each type to have somewhat different color characteristics and overall lamp efficiency. Mercury vapor lighting is the oldest HID technology. The mercury vapor produces a bluish light that renders colors poorly. Therefore,

most mercury vapor lamps have a phosphor coating that alters the color temperature and improves color rendering to same extent. Although they are not the most efficient, they are often used because of their longer lifetime with respect to the other types of HID lamps. Concerning sodium lamps, high-pressure sodium sources were developed primarily for their energy efficiency. Mercury and sodium vapors in the ceramic arc tube produce a yellow/orange light with extremely high LPW performance and exceptionally long service life (up to 40,000 hours). High-pressure sodium lamps render colors poorly, which tends to limit their use to outdoor and industrial applications where high efficacy and long life are priorities. Metal halide lamps are among the most energy efficient sources of white light available today. These lamps feature special chemical compounds known as “halides” that produce light in most regions of the spectrum. They offer high efficacy, excellent color rendition, long service life and good lumen maintenance. Because of their numerous advantages, metal halide lamps are used extensively in outdoor applications and in commercial interiors. An example of an HID lamp is illustrated in *Figure 3*.

Figure 3. HID lamp



As shown, it is composed of two coaxial bulbs. The inner tube that generates the arc is housed in a protective glass envelope that also functions to filter UV rays produced during the ionization of the gas in the inner tube. Unlike ballast for fluorescent tubes that generally make use of a relatively high switching frequency converter, the HID lamps are supplied with low-frequency square waves (150 Hz to 800 Hz) to avoid damage from acoustic resonance. The acoustic resonance may cause arc instability, fluctuation in light output, and in the worst case a cracking of tubes. In practice, the designer must ensure that the ripple current is well below 20% to prevent the acoustic resonance in a low-frequency square wave operation.

2.1 HID ballast requirement

Like any gaseous discharge light source, HID lamps have their own special electrical requirements that must be supplied by the ballast circuitry according to the power and the type of HID itself. HID lamps require a high ignition voltage (2 kV to 5 kV) and even higher (>20 kV) when the lamp is hot. In addition, an HID lamp requires a warm-up period to achieve its full light output. Even a momentary loss of power can cause the system to re-strike and have to warm up again (a process that can take up to several minutes). The lamps used for this design are:

1. Osram power ball HCI-T35W/830WDL
2. Philips mastercolor CDM-T 35W/830

whose characteristics are given in *Table 1* and *Table 2* respectively.

Table 1. Osram HID

Parameter	Value	Unit
Lamp wattage	37	W
Lamp voltage	90	V
Ignition voltage min./max.	3.5 / 5	kV
Lamp current	0.5	A
Nominal luminous flux	3400	Lm
Luminous efficacy	92	Lm/W
Color temperature	3000	K
Color rendering index	84	Ra
Base	G12	
Light center length	56	mm
Length	100	mm
Average lamp life	12000	h
Burning position	Universal	

Table 2. Philips HID

Parameter	Value	Unit
Lamp wattage	38	W
Lamp voltage	88	V
Ignition voltage min./max.	5	kV
Lamp current	0.53	A
Nominal luminous flux	3300	Lm
Luminous efficacy	93.3	Lm/W
Color temperature	3000	K
Color rendering index	81	Ra
Base	G12	

Table 2. Philips HID (continued)

Parameter	Value	Unit
Light center length	56	mm
Length	100	mm
Average lamp life	6000 to 50% survival	h
Burning position	Universal	

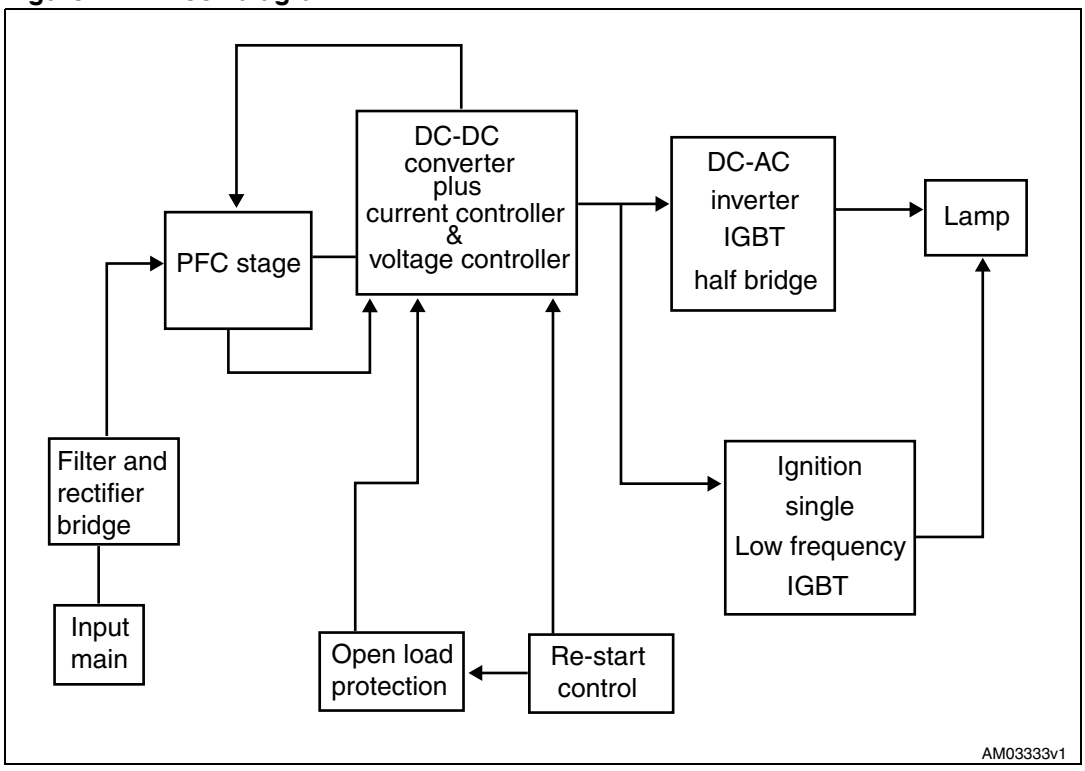
2.2 Block diagram

The ballast is composed of 4 main blocks:

- A boost converter with a function of power factor correction pre-regulator (PFC)
- A fly-back converter with a function of DC-DC converter
- The half-bridge inverter to drive the lamp with low-frequency square waves
- The ignition circuit to warm up the lamp

Figure 4 illustrates the block diagram of the 35 W HID ballast.

Figure 4. Block diagram



The HID ballast block diagram includes:

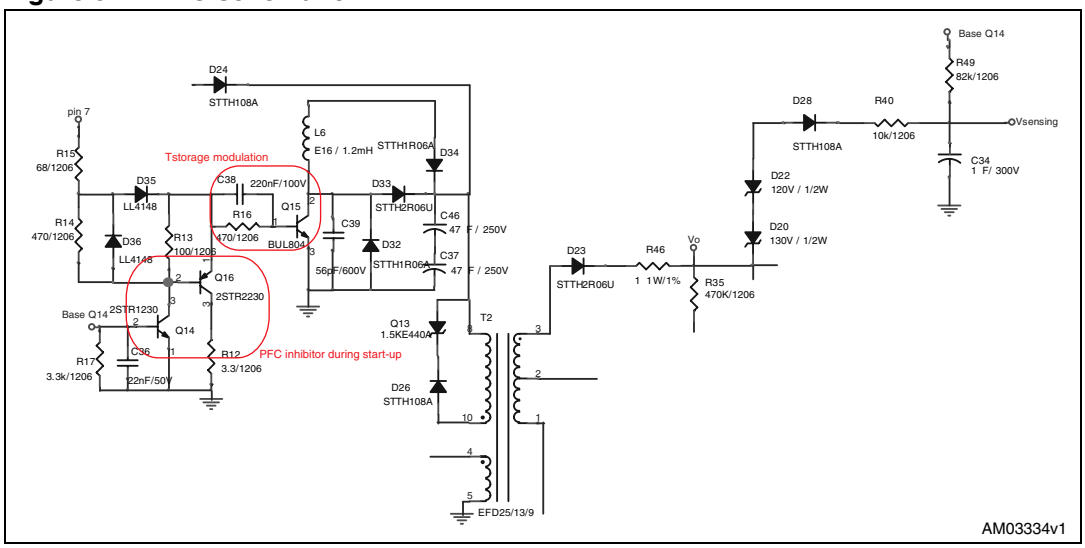
- an EMI filter
- a bridge rectifier
- a boost converter for PFC
- a DC-DC converter to control the lamp current and power
- a DC-AC inverter for driving the lamp at low frequency
- a re-start control
- an open-load protection
- an ignition circuit (starter)
- various driver ICs and circuitry for controlling the different blocks

The complete electrical schematic diagram of the board as well as the board layout and the bill of material (BOM) are given in *Appendix B: Bill of material*.

3 PFC section

The PFC pre-regulation circuit is a boost converter working in discontinuous mode. It makes use of a power bipolar transistor as the main switch and no dedicated IC is used to generate the proper PWM signal. The physical relation existing between the collector current (I_C) and storage time (ts) of any power bipolar transistor is exploited to generate the PWM signal. In fact the overall switch-on time is given by the sum of “IBON time” plus the storage time. Therefore keeping the “IBON time” constant, the duty-cycle changes according to the ts modulation. This natural duty-cycle variation generates an appropriate PWM signal to control the PFC stage. To drive the power bipolar transistor we use the same L6562D output used in the DC-DC fly-back converter with a fixed duty-cycle to regulate the lamp power. *Figure 5* illustrates the electrical schematic related to the PFC stage.

Figure 5. PFC schematic



For a better understanding of the proper design of the above described PFC circuit, the user may refer to the application note AN2349. The equations needed to calculate the inductance value and capacitance value are given as follows.

The PFC inductor is given by equation 1:

Equation 1:

$$L = \frac{P}{f} * \left(\frac{t_A + t_B}{T}\right)^2 * \left(\frac{1}{I_M^2}\right) * \left(\frac{V_{OUT} - V_M}{V_{OUT}}\right) = 1.2mH$$

where:

- P is the input power
- f is the operating frequency
- $(t_A+t_B)/T$ is chosen as 0.7 in order to ensure that the circuit remains in the discontinuous mode leaving a deadtime of 0.3 T,
- V_{OUT} is the PFC output voltage, imposed at 460 V

The output capacitor is given by equation 2:

Equation 2:

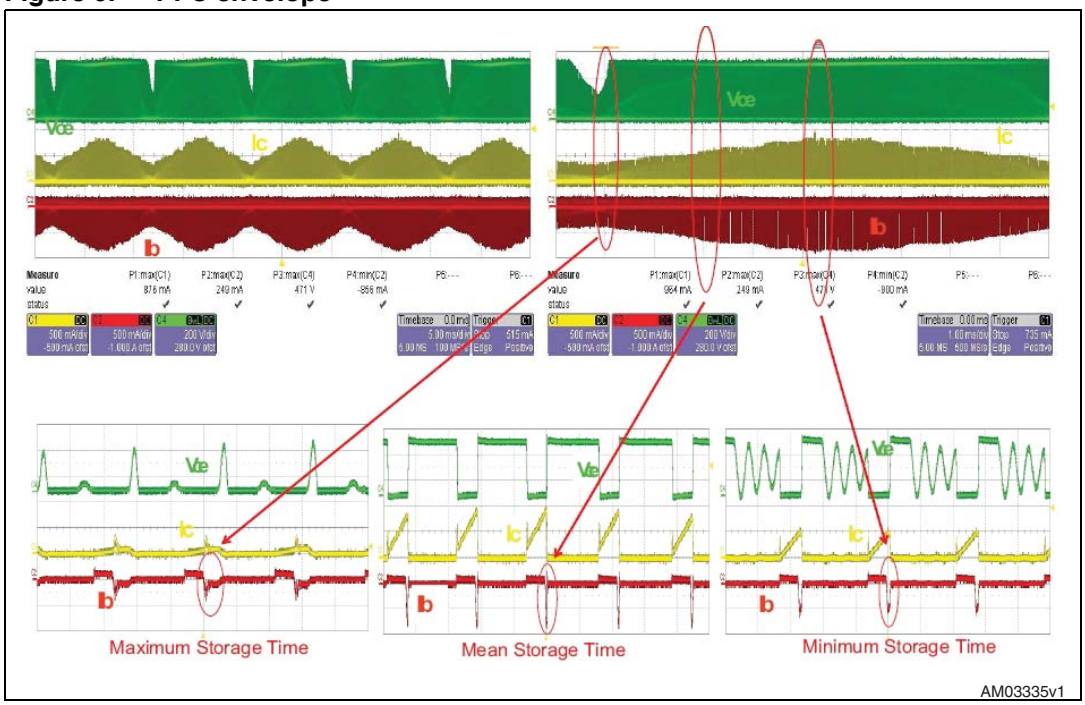
$$C_{OUT} = \left(I_M - \frac{2 * I_M}{\pi} \right) * \frac{1}{2\pi f^* V_{ppripple}} = 21\mu F$$

where:

- $f^* = 2\ f = 100$ Hz
- $V_{ppriple}$ is the peak-to-peak ripple voltage

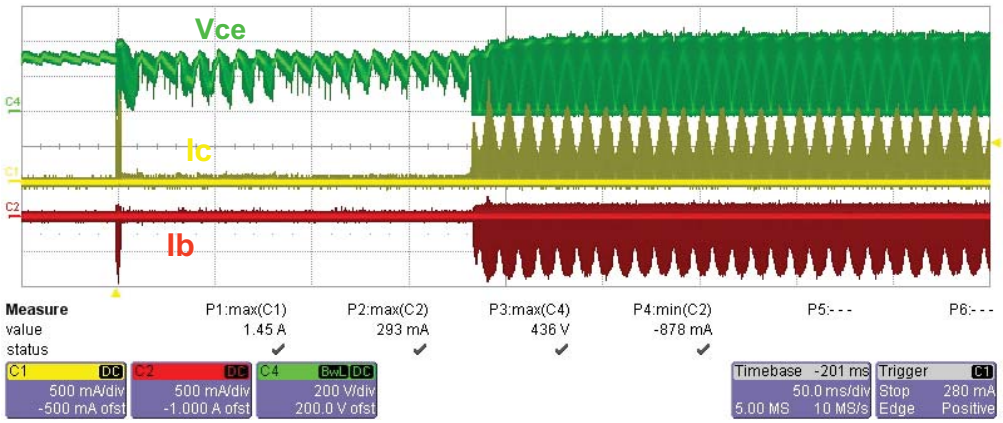
For the actual demonstration board two capacitors of 47 µF / 300 V in series have been used since the output voltage at startup may exceed 550 V. *Figure 6* shows the storage time modulation in the PFC section.

Figure 6. PFC envelope



During the startup phase the PFC stage has to be inhibited since the output voltage V_0 is as high as ~550 V, therefore the duty cycle increases with consequent excessive current on the PFC power switch. This effect could cause device failure. In fact, during the startup phase, when the voltage on the secondary side is higher than 250 V (Zener diodes D20 and D22), a low current flows on the base of the Q14 transistor (see *Figure 5*) which starts conducting, disabling the PFC circuit. After startup, the output voltage V_0 on the secondary side of the transformer decreases, the bipolar Q14 switches off, and the PFC starts working. *Figure 7* shows the waveform during the startup phase in which this effect is highlighted.

Figure 7. PFC detail during startup



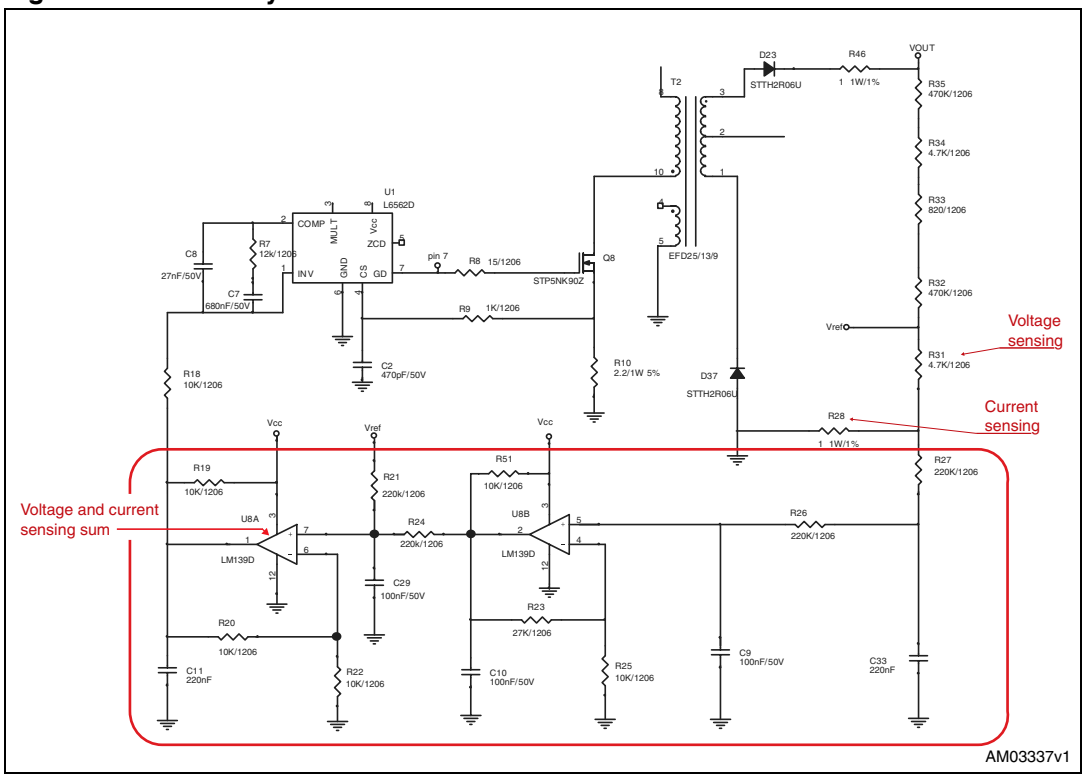
4 DC-DC fly-back converter design

The fly-back converter uses a central taped transformer. This allows us the use of two small capacitors (some hundreds of nF), to create the Vcc/2. In this way the lamp frequency can be set at about 200 Hz without using electrolytic capacitors that wouldn't permit precise control of the lamp current. In order to guarantee the stability and the regulation of the lamp current, some important conditions must be considered.

- The voltage on the output electrolytic capacitor that feeds the fly-back converter has to be very stable;
- The driver used in the DC-DC converter (L6562D) is generally used for PFC function. Unlike the PFC function here, the multiplier input (pin 5) is connected to a stabilized voltage that allows having a constant current envelope (necessary to proper feed the lamp) at the output of the fly-back;
- The two secondary sides of the fly-back that supply the lamp, through the half-bridge, provide a current with stable amplitude, where the high-frequency ripple is minimized by the two non-electrolytic capacitors C12 and C22. These two capacitors only have to filter the operating frequency of the fly-back (50 kHz-100 kHz), but they do not have to store high energy that would impose a fixed voltage on the lamp, thus reducing the lamp current control.

The power regulation uses the sum method that has the function to regulate the lamp power by two sensing signals on the two secondary sides of the DC-DC transformer T2. The current control is performed by reading the signal on the sensing resistor RI, while the voltage control is performed by reading the signal on the sensing resistor Rv. These two signals are then added in order to create the error signal to regulate the lamp power. In particular during startup this control assures a square wave voltage (about 200 Hz) of +/- 280 V on the lamp, with additional voltage spikes of 2.5 kV-3 kV from the ignition circuit. After the ignition, the voltage spikes disappear and the square wave voltage suddenly decreases down to ~40% of the steady-state value and the current control takes over regulating the power. Firstly the power delivered to the lamp is about 60% of its nominal value and after about one minute it reaches its steady-state value. *Figure 8: DC-DC fly-back converter with the sum method control on page 14* shows the DC-DC fly-back converter schematic where the sum method control used for the power control has been encircled.

Figure 8. DC-DC fly-back converter with the sum method control



The proposed technique controls the sum of two weights assigned to V_{LAMP} and I_{LAMP}, maintaining constant this sum. Following is an example of the power regulation obtained using this method. The lamp power is given by:

Equation 3

$$P_{LAMP} = V_{LAMP} * I_{LAMP} = K$$

Setting the:

- Typical value of V_{LAMP} = X, with a variation of + 10%
- Typical value of I_{LAMP} = Y, with a variation of + 10%

These two components are added and their sum is kept constant.

Equation 4

$$SUM = X + Y = K$$

Let's fix a weight X at typical value of V_{LAMP} and Y at I_{LAMP}, and assuming the same weight X = Y, the maximum possible variation is:

Equation 5

$$SUM = (X + 10\%X) + (Y - 10\%Y) = K$$

Therefore in terms of power:

Equation 6

$$P_{LAMP} = (X + 0.1X) * (Y - 0.1Y) = XY - 0.01XY = P_{LANMPtyp} - 1\%$$

We can conclude that with a variation of 10% of both V_{LAMP} and I_{LAMP}, the power variation is only 1%. The actual fly-back operates in DCM (discontinuous conduction mode) when the primary current starts from zero at the beginning of each switching cycle. This happens because the secondary of the transformer has discharged all the energy stored in the previous period. The table below lists the converter specification data and the first parameters that a designer has to set from scratch for a new a fly-back converter project. The “Value” column of *Table 3* gives the values of demonstration board STEVAL-ILH002V1.

Table 3. Converter specification data and fixed parameters

Symbol	Description	Value	Unit
V_{DCmin}	Continuous minimum input voltage	380	V
V_{DCmax}	Continuous maximum input voltage	550	V
V_O	Output voltage	210	V
P_O	Output power	37	W
η	Converter efficiency	87%	
F_{min}	Minimum switching frequency	60	kHz
F_{max}	Maximum switching frequency	100	kHz
$V_{flyback}$	Reflected fly-back voltage	175	V
V_{spike}	Max overvoltage	125	V

Transformer design is the major part of a fly-back project. A few degrees of freedom are available to the designer starting from the target data and most of them are linked to each other so that the final project is often achieved by repetition. The first choice to be made is the transformer turn ratio NP / NS, where NP and NS are respectively the number of primary and secondary windings. The calculation of the turn ratio is correlated to the maximum voltage rating of the transistor to be used as the primary switch. In fact looking at *Equation 7* for fly-back operation, the voltage at the power switch drain is given by:

Equation 7

$$V_T = V_{DCmax} + \frac{N_P}{N_S}\left(V_o + V_{F,diode}\right) + V_{spike} + margin$$

where

Equation 8

$$\frac{N_P}{N_S}\left(V_o + V_{F,diode}\right) = V_{flyback} = flybackvoltage$$

and V_{spike} = the maximum overvoltage that must be chosen, ensuring that the total voltage across the power switch does not exceed the maximum breakdown voltage of the device chosen as the power switch. For the actual demonstration board, with STF5NK90Z we can set:

- Margin = 50 V
- V_{spike} = 125 V

From *Equation 7*, neglecting $V_{F,diode}$ (lower than 1V), the V_{Fl} results in 125 V and we can now easily calculate the transformer turn ratio:

Equation 9

$$\frac{N_P}{N_S} = \frac{V_{flyback}}{V_o} = 0.83$$

Once the turn ratio is calculated, the second step is to ensure that the converter operates in discontinuous mode. Equation 10 guarantees that the energy on the primary coil is completely transferred to the secondary coil before the next cycle occurs.

Equation 10

$$V_{DCmin} * T_{ONmax} = \frac{N_P}{N_S}\left(V_0 + V_{F,diode}\right)T_{RESET} = V_{fl} * T_{RESET}$$

A safety margin of 20% is recommended to guarantee the complete demagnetization of the primary side (see equation 11).

Equation 11

$$T_{ONmax} + T_{RESET} = 0.8T_S$$

where T_{ONmax} is the maximum on-time, T_{RESET} is the time needed to demagnetize the transformer inductance and T_S is the switching time. Combining *Equation 10* and *Equation 11*, T_{ONmax}, may be calculated using *Equation 12*.

Equation 12

$$T_{ONmax} = \frac{V_{fl} * 0.8 * T_{Smin}}{V_{DCmin} + V_{fl}} \cong 4.2\mu sec$$

The next step is to calculate the peak current. Setting the output power to 37 W and the desired efficiency (88% in this case), we also have the freedom to choose the switching frequency. An operating frequency range of 60 kHz - 100 kHz has been selected. The first step is to calculate the primary inductance. By using an approximated formula that does not take into account the losses on the power switch, nor on the input bridge nor on the rectified network, we have:

Equation 13

$$P_{IN} = 1.15 * P_{OUT} = \frac{\frac{1}{2} L_P I_P^2}{T_S} = \frac{\frac{1}{2} V_{DCmin}^2 * T_{ONmax}^2}{L_P * T_S}$$

hence

Equation 14

$$L_P = \frac{V_{DCmin}^2 * T_{ONmax}^2}{2.3 * P_{OUT} * T_{Smin}} = 1.8mH$$

From here now we can calculate the peak current on the primary side:

Equation 15

$$I_P = \frac{V_{DCmin} * T_{ONmax}}{L_P} \cong 880mA$$

It is also important to determine the I_{RMS} primary current value (see *Equation 16*) and I_{RMS} secondary current value (see *Equation 13*) to correctly dimension the wire size of the windings:

Equation 16

$$I_{RMSprimary} = \frac{I_P}{\sqrt{3}} \sqrt{\frac{T_{ONmax}}{T_S}} = 255mA$$

Equation 17

$$I_{RMSsecondary} = \frac{I_S}{\sqrt{3}} \sqrt{\frac{T_{RESET}}{T_S}} = 312mA$$

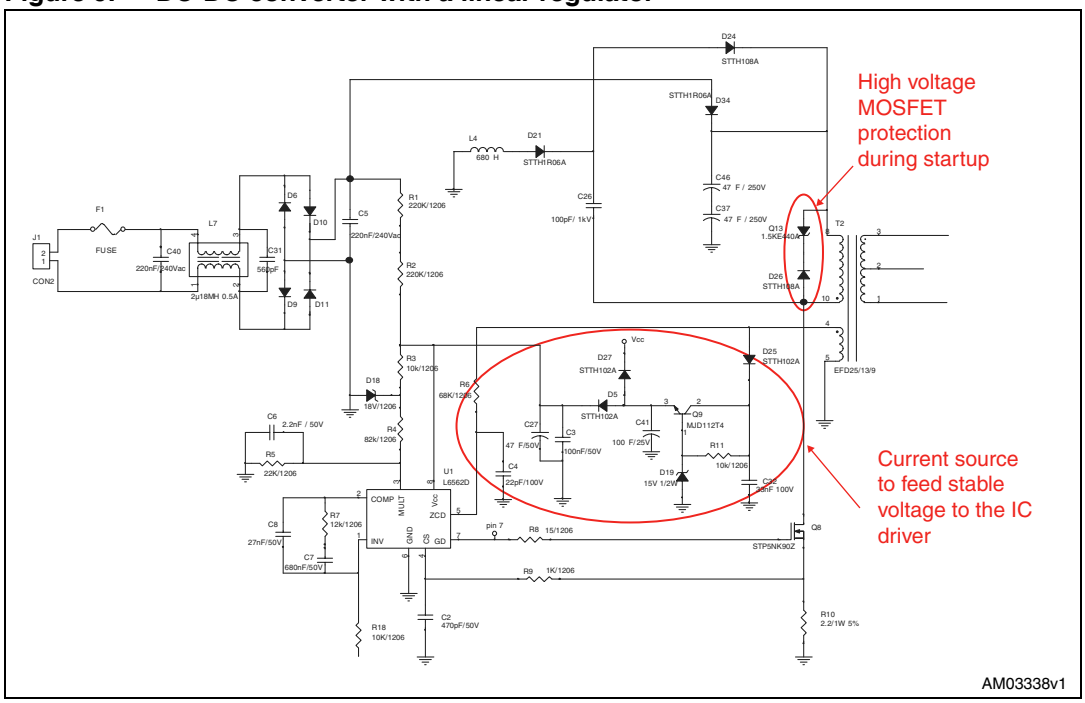
where “I_S” is the peak current on the secondary side:

Equation 18

$$I_S = \frac{N_P}{N_S} I_P = 730mA$$

Figure 9 shows the DC-DC fly-back converter schematic where a linear regulator connected on the auxiliary winding has been encircled:

Figure 9. DC-DC converter with a linear regulator



The auxiliary winding gives the signal to drive the L6562D IC. Since the output voltage of the DC-DC converter during the lamp startup changes from 550 V down to 60 V, in this phase the MJD112T4 (a Darlington npn transistor) assures very low V_{CC} variations from about 16V to about 11V, that is the minimum value to avoid driver switch-off. Assuming that the voltage on the auxiliary winding changes from ~100 V during startup down to ~11.5 V to go around 30 V in steady-state, we can set the auxiliary winding number using equation 19.

Equation 19

$$N_{AUX} = \frac{V_{AUX}}{V_S} N_S = 18$$

Another function of the auxiliary winding is to verify the complete demagnetization of the transformer through the ZCD pin (pin 5).

Figure 10. V_{CC} driver regulation through MJD112T4

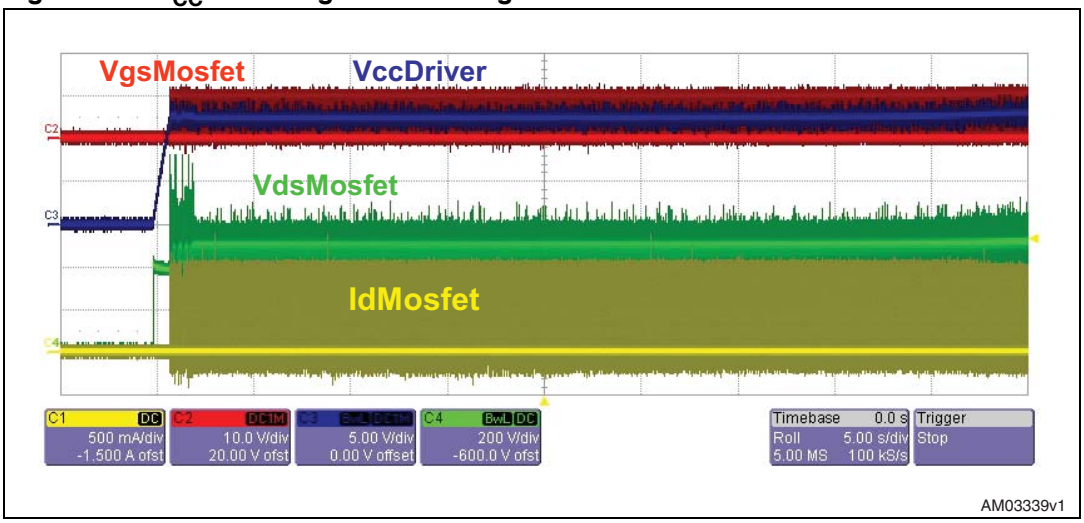
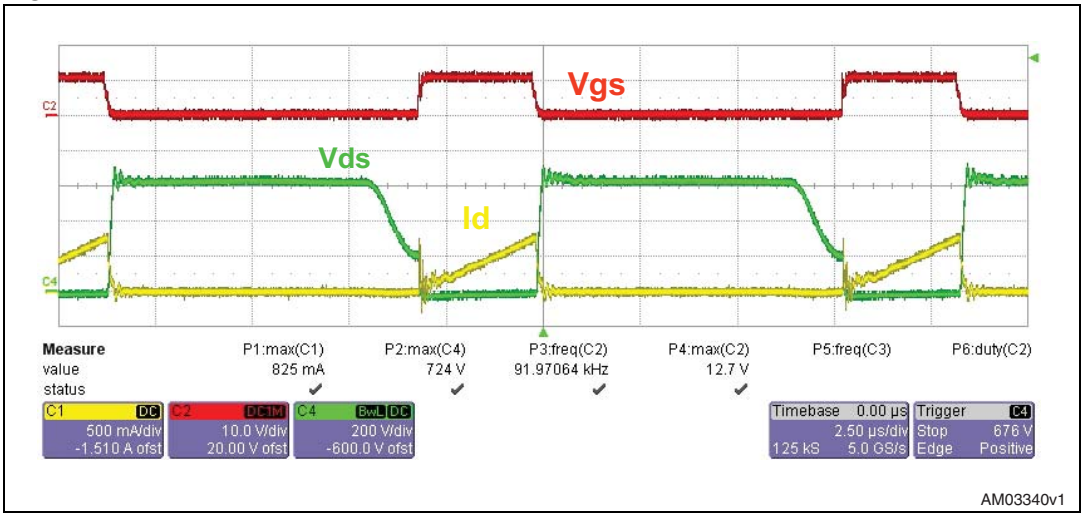


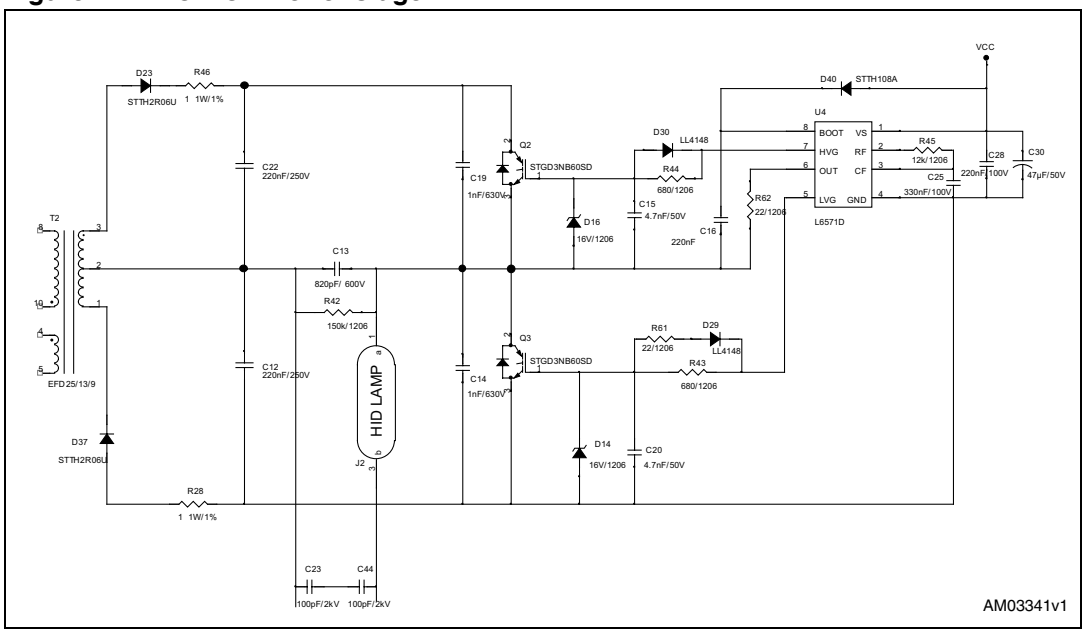
Figure 11. STF5NK90Z in DC-DC converter



5 DC-AC inverter and lamp

The DC-AC inverter stage uses a half-bridge topology, with two IGBTs driven by the L6571A driver (*Section Appendix D: L6571A high-voltage half-bridge driver with oscillator on page 36*). The complete electrical schematic is illustrated in the following *Figure 12*.

Figure 12. DC-AC inverter stage



The frequency of the internal oscillator can be programmed using an external circuitry composed of a resistor RF and a capacitor CF. The nominal oscillator frequency can be calculated using the following equation 20:

Equation 20:

$$f_{OSC} = \frac{1}{2RC\ln 2} = 180Hz$$

Taking into consideration that the HID lamps operate at low-frequency square wave (150 Hz to 800 Hz) to avoid damage from acoustic resonance, and considering that the maximum output voltage V_0 is equal to 550 V, the best choice is to use STGD3NB60SD, that is a PowerMESH™ n-channel IGBT 600 V 3 A with monolithic diode. This device has a high-voltage technology based on a patented strip layout, with outstanding performance. The suffix "S" identifies a family optimized to achieve minimum on-voltage drop for low-frequency applications (<1 kHz). The main characteristics of this device are as follows:

- V_{CES} = 600 V
- $V_{CE(sat)(max)}$ < 1.5 V
- I_C = 3 A
- High input impedance (voltage driven)
- Very low on-voltage drop
- High current capability
- Integrated wheeling diode

Figure 13 through *Figure 16* show the IGBT working during steady-state operation with the details of turn-off and turn-on:

Figure 13. STGD3NB60SD in steady-state operation

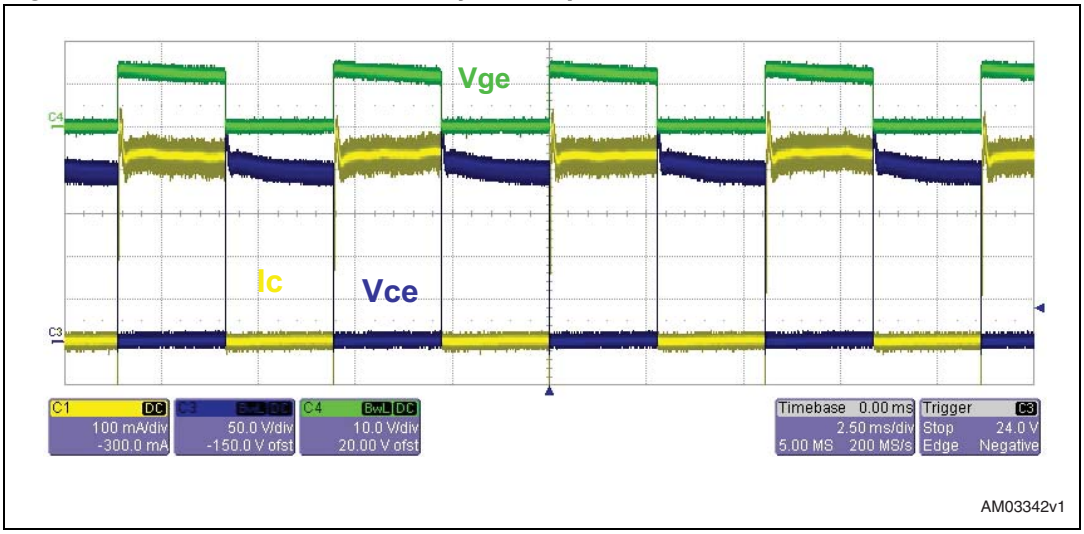


Figure 14. STGD3NB60SD details during steady-state operation

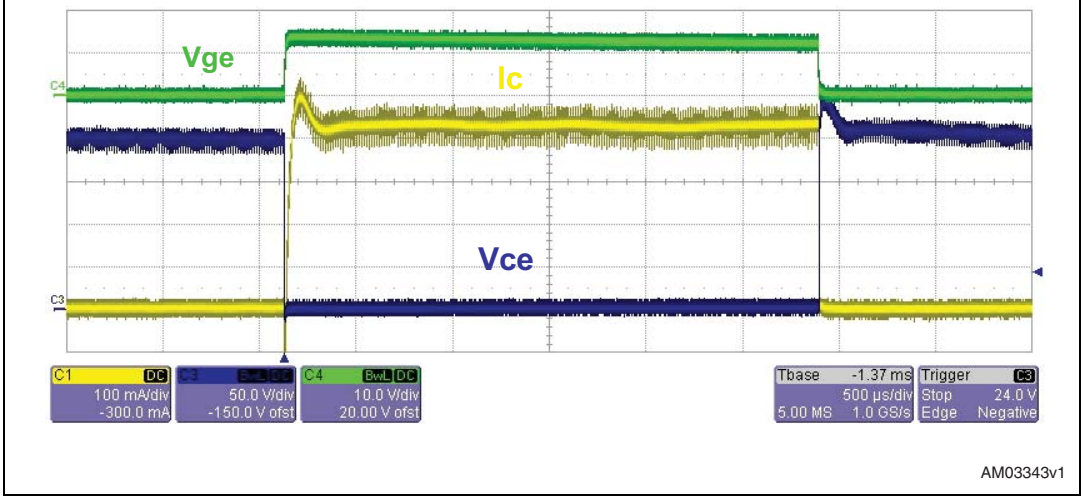


Figure 15. Detail during turn-on

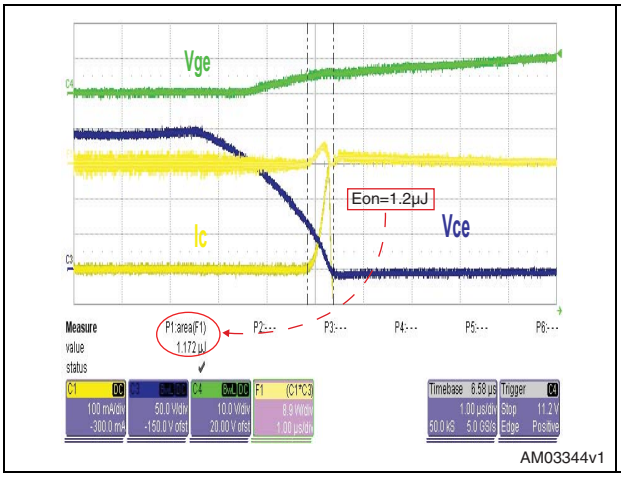
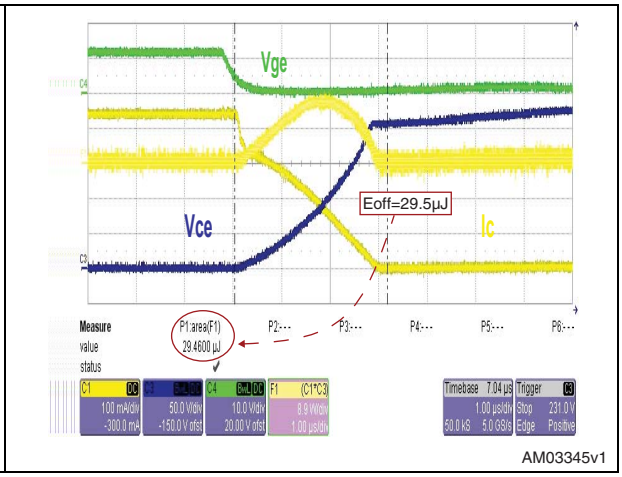


Figure 16. Detail during turn-off



The power dissipation due to E_{ON}+E_{OFF} at frequency = 180 Hz is given by the following equation 21:

Equation 21:

$$P_{SWITCH} = 30.7 * 10^{-6} * 180 = 5.5mW$$

The power dissipation due to conduction is given by equation 22:

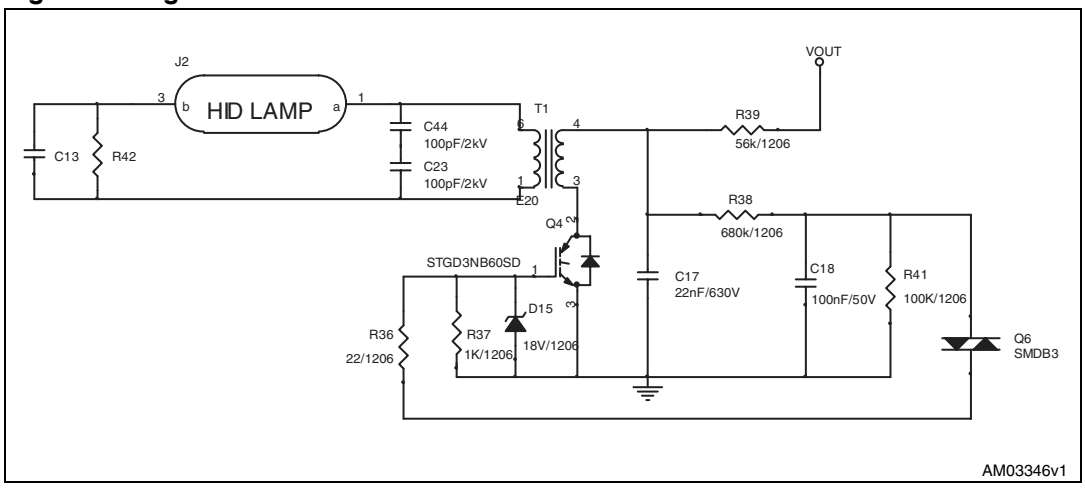
Equation 22:

$$P_{ONstate} = V_{CE} * I_C * duty - cycle = 0.9V * 0.4A * 50\% = 180mW$$

6 Ignition stage

The only function of an ignitor is to deliver the proper high-voltage ignition for starting the discharge in an HID lamp. Once the lamp is ignited, the voltage falls to a lower voltage of the order of 30 V and the lamp is maintained for a short time (typically between 1-2 minutes) in “current mode” where the current is constant, but higher than steady state. The voltage rises slowly until the lamp reaches nominal power, properly decreasing the lamp current. After ignition, the ignitor has to stop producing ignition peaks. The voltage level at which an HID lamp ignites is called its ignition voltage which depends on the lamp temperature. With cold lamps the required voltage value for starting the discharge is very high, typically about 2 kV - 3.5 kV. When the lamp is hot, in order to ensure the immediate HID lamp restart, very high peak voltages (about 20 kV) are necessary. For this reason in order to re-ignite a hot lamp, several minutes are necessary for the lamp to cool. The following *Figure 17* shows the ignition circuit.

Figure 17. Ignition circuit



The ignition circuit acts only during startup, when the output voltage is very high. This stage uses a high-voltage switch (600 V) with a high rush current, typically an IGBT, driven by a network composed of a resistor R, a capacitor C and a diac and a transformer that delivers voltage spikes of 3 kV on the lamp. The choice for such an IGBT is due to the fact that a V_0 of 550 V is at the primary side of T1 and therefore on the IGBT. The voltage divider has been set in order to have a voltage equal to ~41 V which is a sufficient voltage to trigger the diac. When the output voltage V_0 reaches 500 - 550 V, through the IGBT conduction, the capacitor discharges its stored energy on the primary side of the transformer. This voltage-current pulse reflects on the secondary side of the transformer providing the voltage necessary of ~3.0 kV to activate the lamp. The major part of this section is the transformer design. The first choice to be made is the inductance value which depends on the maximum ripple on both current and voltage as shown in equation 23:

Equation 23:

$$L = \frac{\Delta V}{\Delta I} T$$

where, ΔV and ΔI are respectively the max. variation of the lamp voltage and current. Assuming that the lamp current, I_{LAMP} = 0.53 A and the max current ripple, ~3%, from equation 24we obtain:

Equation 24:

$$\Delta I = 0.03 * I_{LAMP} = 16mA$$

At this point the max. voltage ripple must be calculated. For this reason, considering the triangular current shape, we can calculate the amount of charge stored in the secondary side of the transformer, that is the area of the triangle whose base is the time T_R needed to demagnetize the transformer inductance and whose height is the maximum current on the secondary side (see *Equation 18*). It is given by equation 25:

Equation 25:

$$Q = \frac{I * T_R}{2} = 0.96\mu C$$

where T_R is given by equation 26:

Equation 26:

$$T_R = \frac{V_{DC}}{V_O \frac{N_P}{N_S}} = 2.64\mu sec$$

therefore,

Equation 27:

$$\Delta V = \frac{Q}{C} = 8.7V$$

Now from equation 28 resolving for L, we have

Equation 28:

$$L = \frac{\Delta V}{\Delta I} T = 3.1mH$$

where

Equation 29:

$$T = T_{ON} + T_R = 5.74\mu sec$$

At this point, the turn ratio is calculated using *Equation 30*:

Equation 30:

$$\frac{N_P}{N_S} = \frac{V_S}{V_P} = 5.45$$

Now knowing the turn ratio, the primary inductance value can be calculated from the following equation 31:

Equation 31:

$$L_P = \left(\frac{N_P}{N_S}\right)^2 * L_S = 150\mu H$$

Figure 18 and *19* show the IGBT working during the lamp startup phase and then the lamp startup evolution.

Figure 18. STGD3NB60SD operation during startup

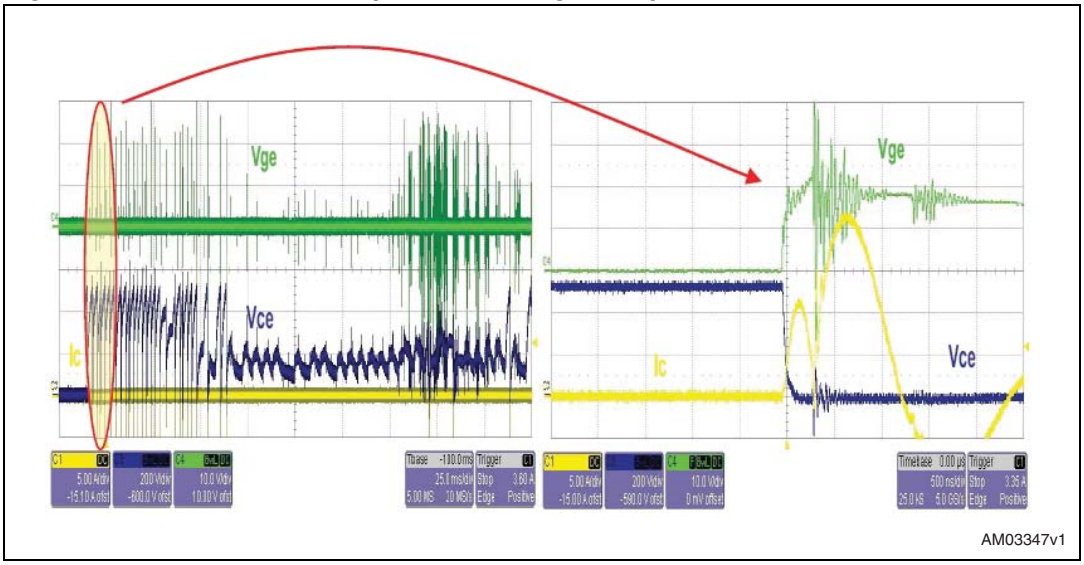
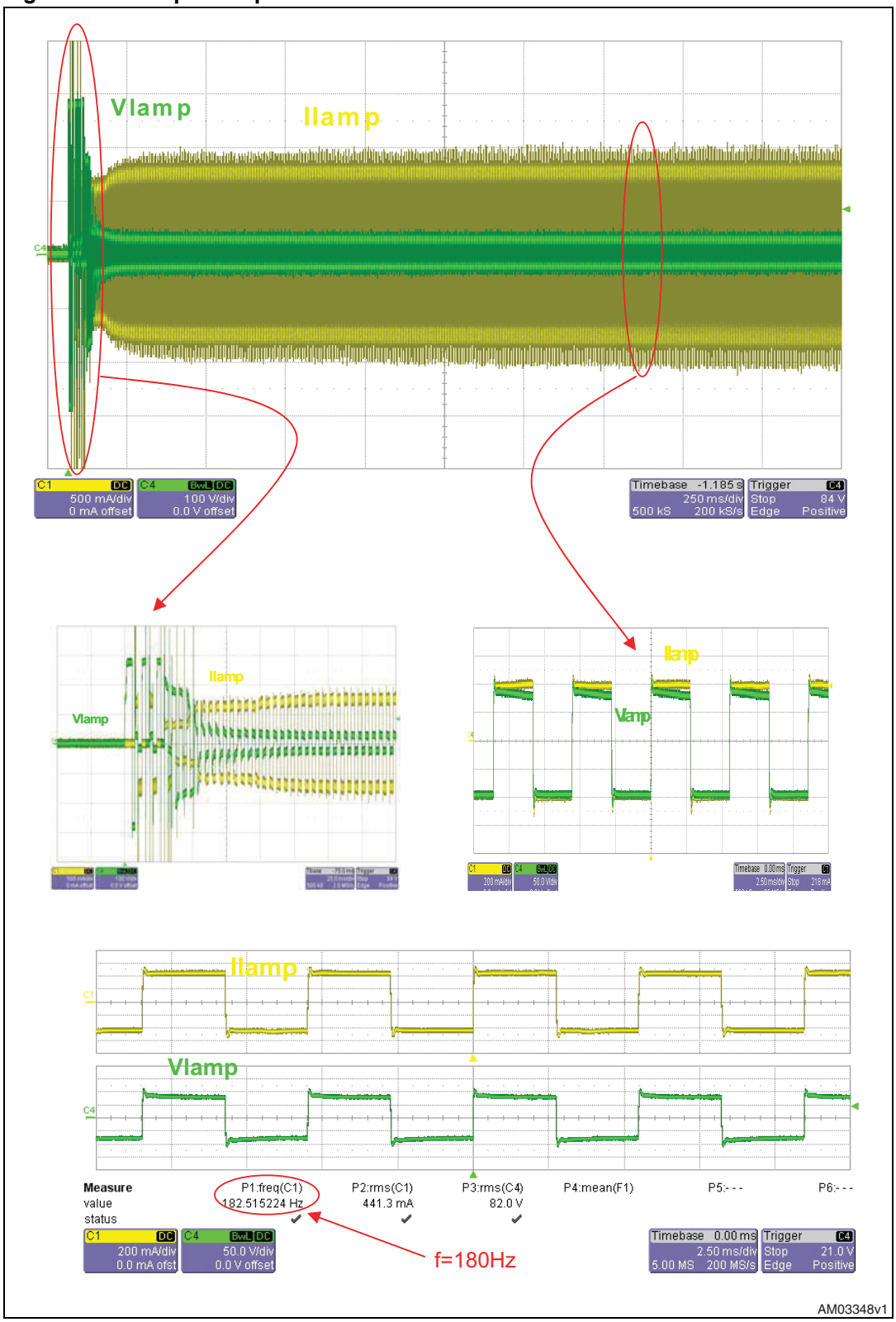


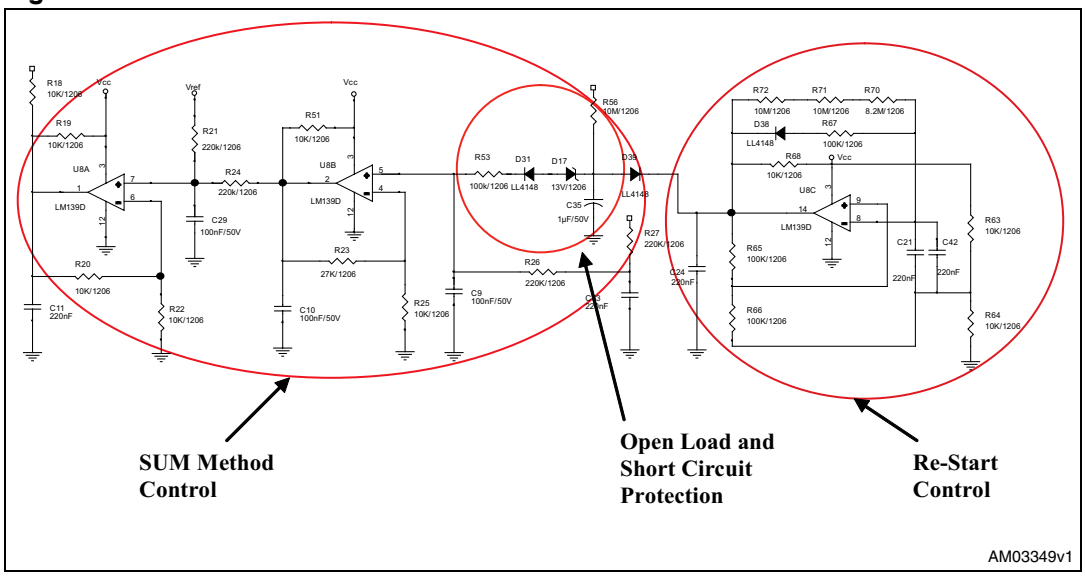
Figure 19. Lamp startup evolution



7 Re-start circuit and open load/short-circuit protection

Figure 20 illustrates in detail the re-start control and the open load/short circuit protection.

Figure 20. Re-start circuit



The function of the re-start block is to try the re-start of the lamp in case of accidental switch-off of the lamp. The number of trys depends on the lamp temperature. In case of open load and short-circuit, the behavior is the same as switch-off. The circuit repeats the re-start every 17 seconds as shown in equation 32:

Equation 32:

$$T_1 = RC\ln\left(1+2\frac{R_2}{R_1}\right)$$

Such circuit control is independent and is composed of an a-stable oscillator. The reference voltage is V_{CC} = 14 V and GND. When the oscillator output is equal to zero, the sum method control acts, giving power to the system that tries to re-start the lamp for 1 sec. This time constant value for re-starting is set by the $R_{26}C_{33}$ network. The open load protection acts during the open load phase during which the voltage is very high. Its function is to clamp the voltage at the Zener diode D17 equal to 13 V. *Figure 21* and *22* show the protection and re-start control.

Figure 21. Re-start control

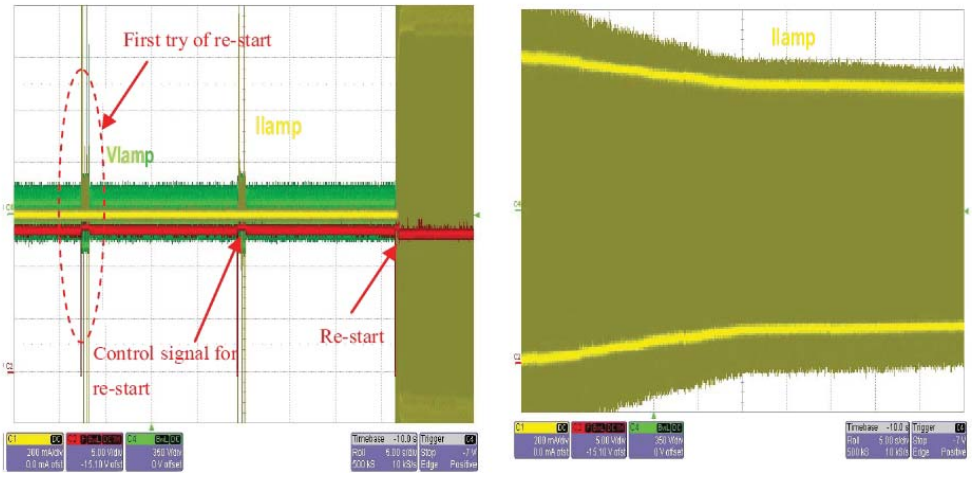
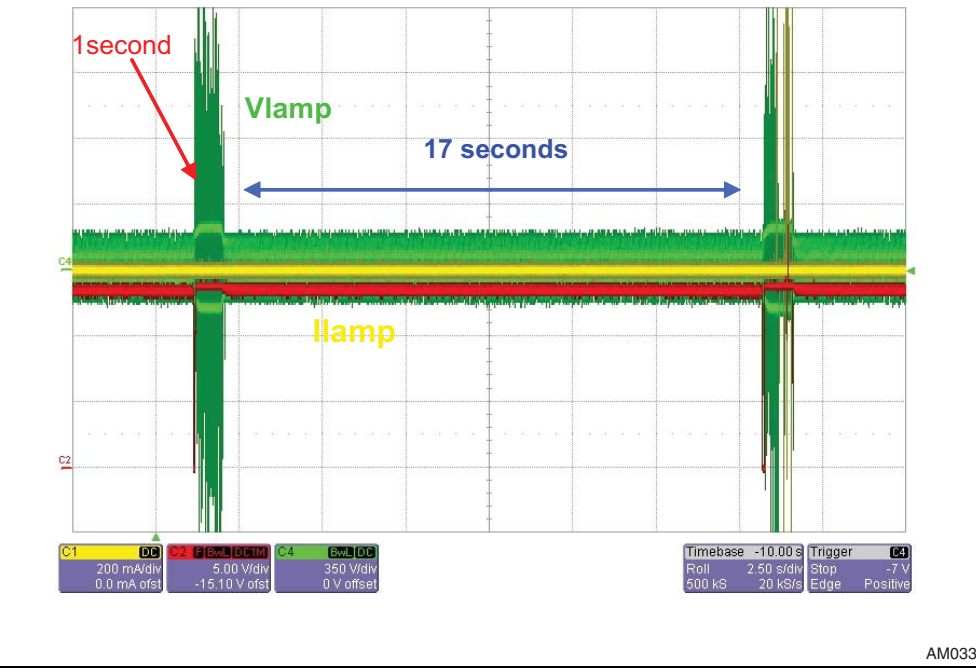


Figure 22. Protection control


1second
Vlamp
17 seconds
Ilamp
C1 DC 200 mA/div 0.0 mA ofst
C2 BwL DC1M 5.00 V/div -15.10 V ofst
C4 BwL DC 350 V/div 0 V offset
Timebase -10.00 s Roll 2.50 s/div 500 kS 20 kS/s
Trigger C4 Stop -7 V Edge Positive
AM03351v1

Appendix A Board description

Figure 23. Board schematic

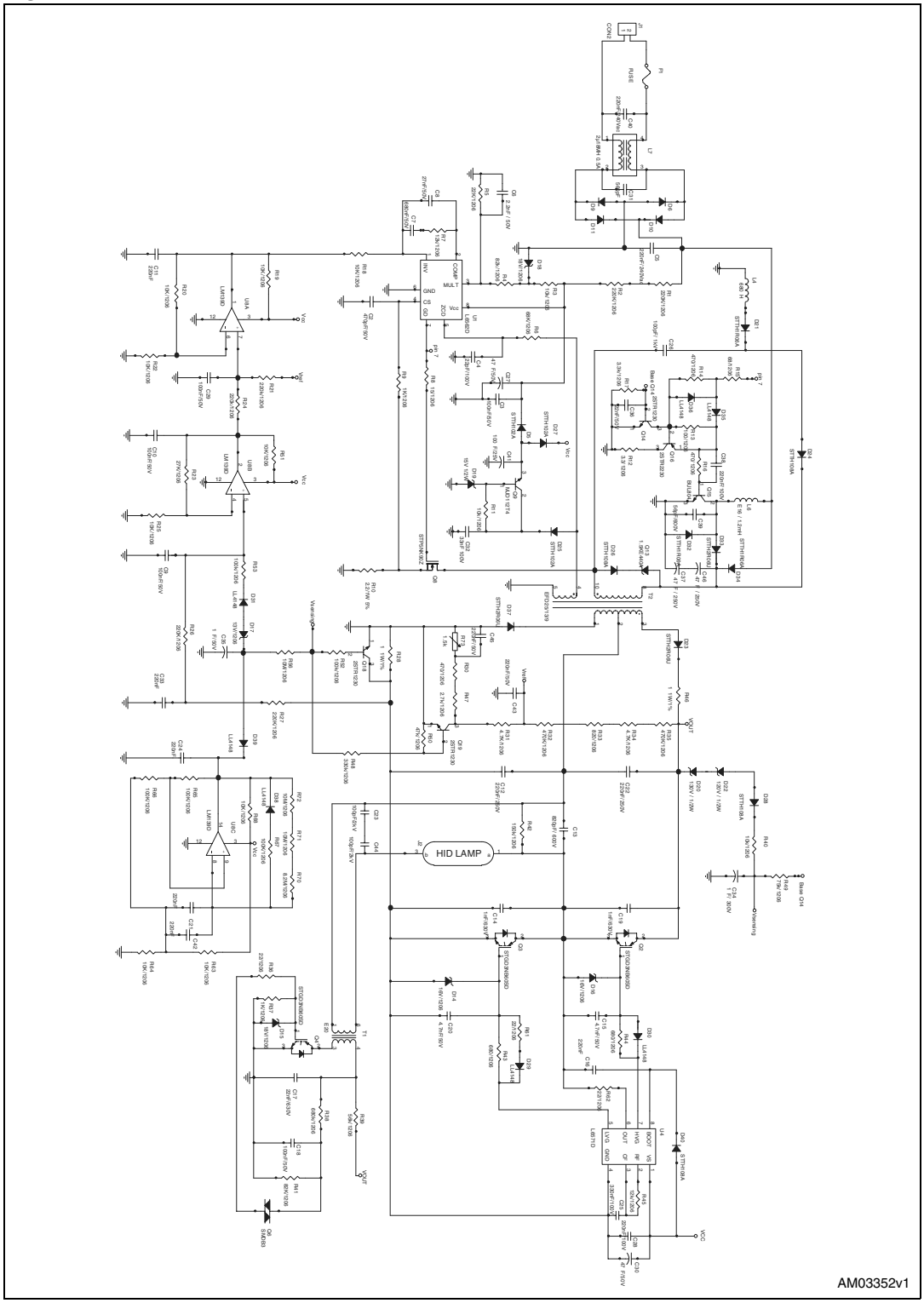


Figure 24. Top board layout

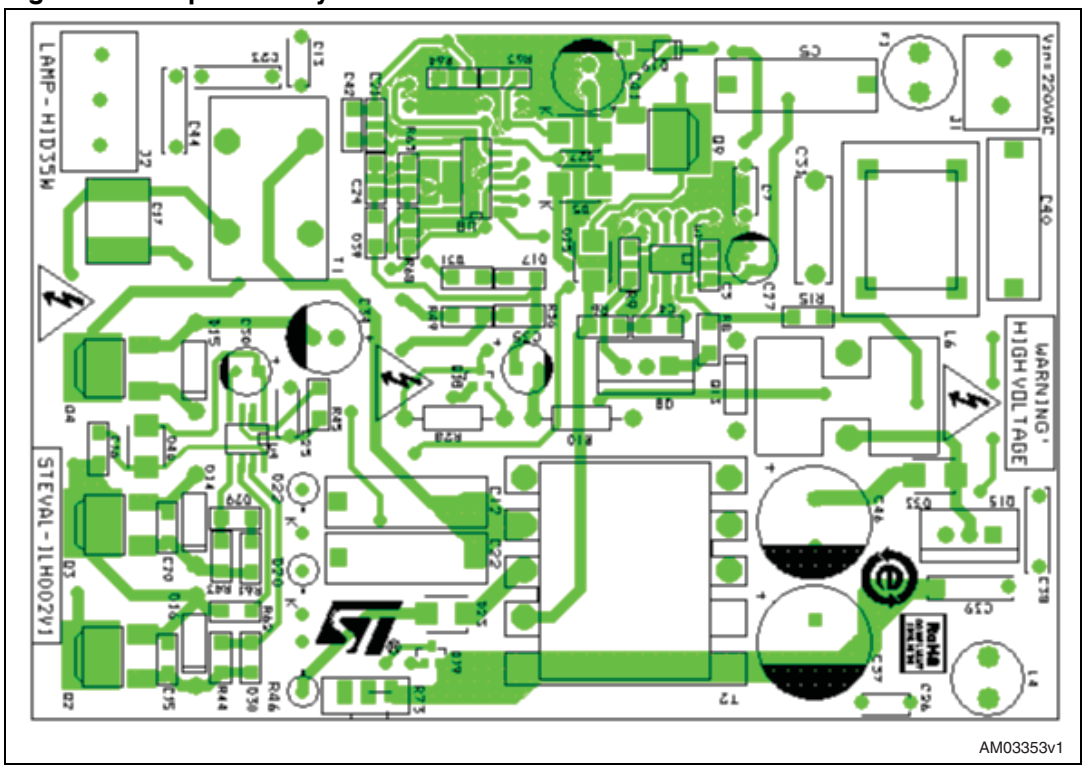
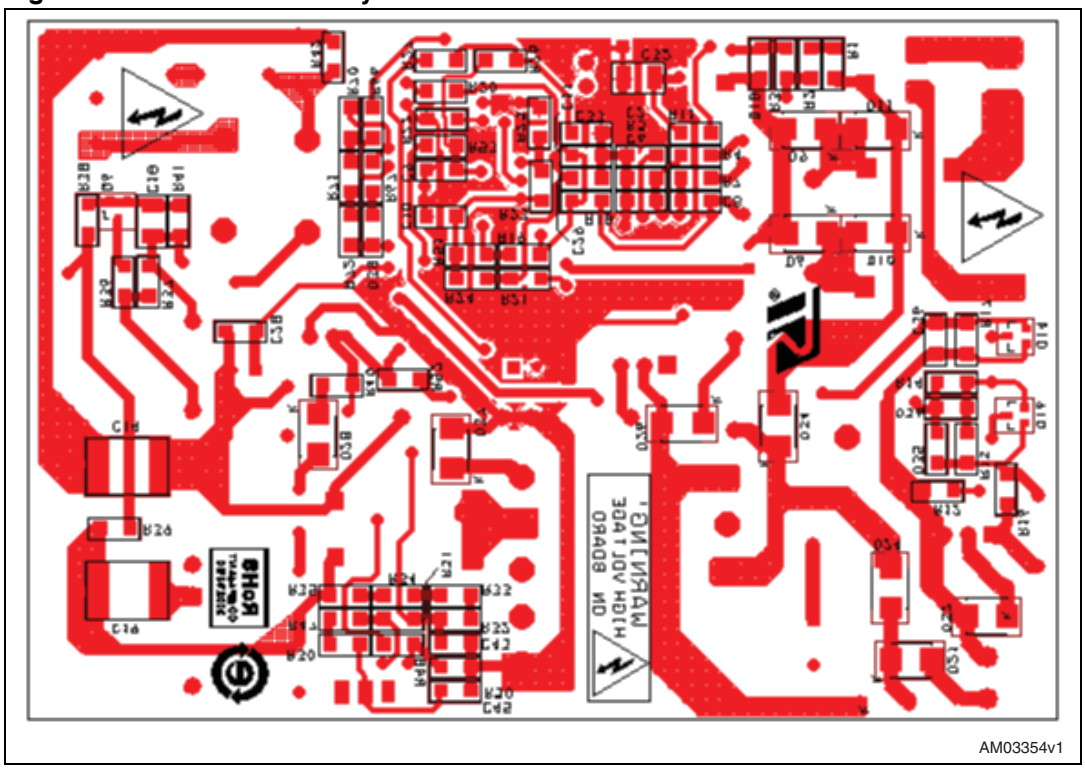


Figure 25. Bottom board layout



Appendix B Bill of material

Table 4. STEVAL-ILH002V1 bill of material

Reference	Qty	Value/part number	Description
C2	1	470 pF / 50 V	SMD 1206
C4	1	33 pF / 100 V	SMD 1206
C5, C40	2	220 nF / 240 V_{AC}	Arcotronics, R46KI3220050M2M
C6	1	2.2 nF / 50 V	Arcotronics, LDECA1220KA0N00
C7	1	680 nF / 50 V	
C8	1	27 nF / 50 V	Arcotronics, LDECA1220KA0N00
C3,C9,C10,C18,C29	5	100 nF / 50 V	SMD 1206
C11,C16,C21,C24,C28, C33,C42,C43,C45	9	220 nF / 50 V	SMD 1206
C38	1	220 nF / 100 V	Polyester capacitor
C13	1	820 pF / 1 kV	Arcotronics, KHA821KN28DHAAA
C14, C19	2	1 nF / 630 V	Arcotronics,LDEPD1100KA5N00
C15, C20	2	4.7 nF / 50 V	Arcotronics, LDECA1470KA0N00
C17	1	22 nF / 630 V	Polyester capacitor
C12, C22	2	220 nF / 400 V	Polyester capacitor MKP
C25	1	330 nF / 50 V	Ceramic capacitor, 50 V, X7R
C26	1	100 pF / 1 kV	Arcotronics, KHB101KN24CGAAA
C23, C44	2	100 pF / 2 kV	Arcotronics, KHB101KP31DGAAA
C27, C30	2	47 µF / 50 V	Arcotronics, ESY476M050AE3AA
C31	1	560 pF / 250 V_{AC}	Arcotronics, KJY561KR35CGAAA
C32	1	33 nF / 100 V	Arcotronics,LDEEB2330KA0N00
C34	1	1 µF / 300 V	Arcotronics, ESH105M350AG3AA
C35	1	1 µF / 50 V	Electrolytic capacitor
C36	1	22 nF / 50 V	Arcotronics, LDECA2220KA0N00
C37, C46	2	47 µF / 300 V	Arcotronics, ESX476M300AL8AA
C39	1	47 pF / 600 V	
C41	1	100 µF / 35 V	Electrolytic capacitor
D5, D25, D27	3	STTH102A	STMicroelectronics, ultrafast diode 1 A
D6, D9, D10, D11	4	SM4007	General-purpose rectifier
D14, D16	2	Zener 16 V	General-purpose Zener, MINI MELF
D15, D18	2	Zener 18 V	General-purpose Zener, MINI MELF
D17	1	Zener 12 V	General-purpose Zener, MINI MELF
D19	1	Zener 15 V	General-purpose Zener, DO41, 1/2 W

Table 4. STEVAL-ILH002V1 bill of material (continued)

Reference	Qty	Value/part number	Description
D20	1	Zener 130 V	General-purpose Zener, 130 V, DO41
D21, D32, D34	3	STTH1R06A	STMicroelectronics, ultrafast diodes, 600 V, 1 A
D22	1	Zener 120 V	General-purpose Zener, 120 V, DO41
D23, D33, D37	3	STTH2R06U	STMicroelectronics, ultrafast diodes, 600 V, 2 A
D24, D26, D28, D40	4	STTH108A	STMicroelectronics, ultrafast diodes, 800 V, 1 A
D29, D30, D31, D35, D36, D38, D39	7	LL4148	General-purpose small signal diode, 100 V, 200 mA, MINI MELF
F1	1	T500 mA / 250 V	Fuse T500 mA, 250 V
J1	1	CON2	Terminal
J2	1	CON3	Terminal
L4	1	680 µH	MAGNETICA, choke, 1551.0006
L6	1	E20, 1.2 mH	MAGNETICA, PFC Coil, 1851.0001
L7	1	2 x 18 mH 0.5 A	Comon mode suppression chokes
T1	1	E20	MAGNETICA high-voltage transformer, 1814.0001
T2	1	EFD25/13/9	MAGNETICA, DC-DC converter, 1318.0006
Q2, Q3, Q4	3	STGD3NB60SD	STMicroelectronics, PowerMESH™ n-channel IGBT 600 V, 3A
Q6	1	SMDB3	STMicroelectronics, DIAC 32 V
Q8	1	STF5NK90Z	STMicroelectronics, Zener-protected Power MOSFET n-channel 900 V, 4.5 A, 2 Ω, TO-220FP
Q9	1	MJD112T4	STMicroelectronics, NPN power Darlington transistor 100 V, 2 A, DPAK
Q13	1	1.5KE440A	STMicroelectronics, Transil, 440 V, 1 A
Q14, Q18, Q19	3	2STR1230	STMicroelectronics, NPN low-voltage power bipolar transistor 30 V, 1.5 A, SOT-23
Q15	1	BUL804	STMicroelectronics, NPN high-voltage power bipolar transistor 800 V, 4 A, TO-220
Q16	1	2STR2230	STMicroelectronics, PNP low-voltage power bipolar transistor 30 V, 1.5 A, SOT-23
R1, R2, R21, R24, R26, R27	6	220 kΩ	SMD 1206

Table 4. STEVAL-ILH002V1 bill of material (continued)

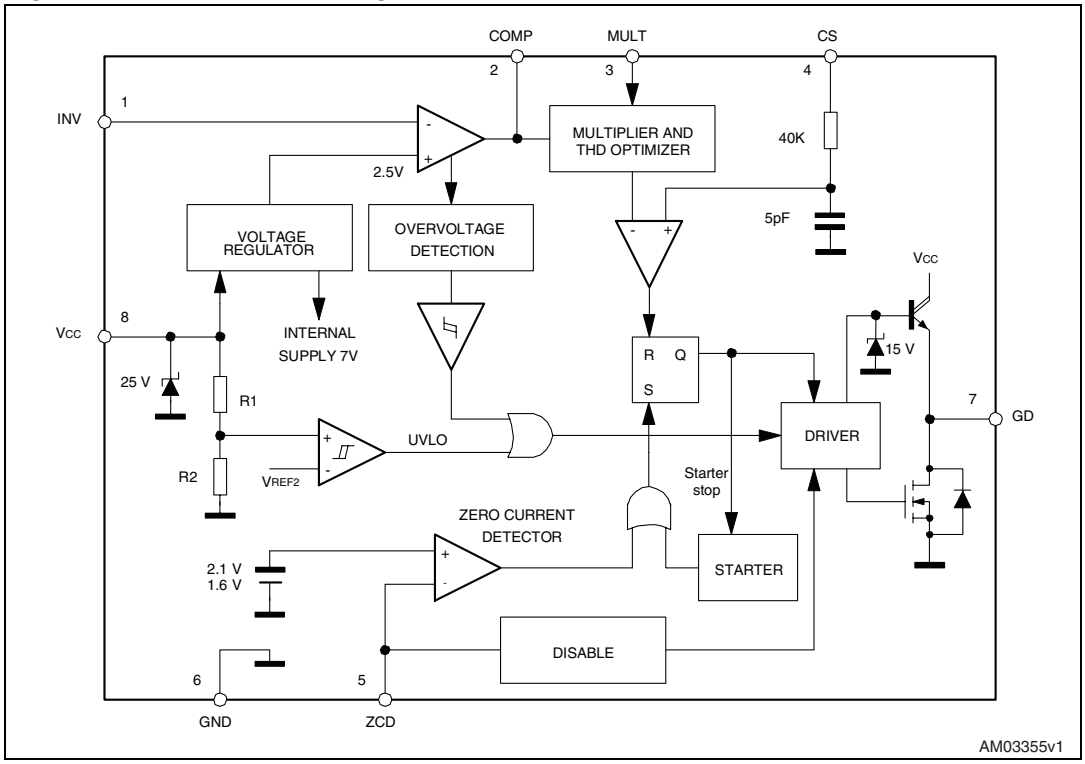
Reference	Qty	Value/part number	Description
R3, R11, R18, R19, R20, R22, R25, R40, R51, R63, R64, R68	12	10 kΩ	SMD 1206
R4	1	82 kΩ	SMD 1206
R49	1	75 kΩ	SMD 1206
R5	1	22 kΩ	SMD 1206
R6	1	100 kΩ	SMD 1206
R7, R45	2	12 kΩ	SMD 1206
R8	1	15 Ω	SMD 1206
R9, R37	2	1 kΩ	SMD 1206
R10	1	2.2 Ω	1 W 5%
R12	1	3.3 Ω	SMD 1206
R13	1	100 Ω	SMD 1206
R14, R16, R30	3	470 Ω	SMD 1206
R15	1	68 Ω	SMD 1206
R17	1	3.3 kΩ	SMD 1206
R23	1	27 kΩ	SMD 1206
R28, R46	2	1 Ω	1 W 1%
R33	1	820 Ω	SMD 1206 1%
R31, R34	2	4.7 kΩ	SMD 1206 1%
R32, R35	2	470 kΩ	SMD 1206 1%
R36, R61, R62	3	22 Ω	SMD 1206 1%
R38	1	680 kΩ	SMD 1206
R39	1	56 kΩ	SMD 1206
R42	1	150 kΩ	SMD 1206
R43, R44	2	680 Ω	SMD 1206
R47	1	2.7 kΩ	SMD 1206 1%
R50	1	47 kΩ	SMD 1206
R48	1	330 kΩ	SMD 1206
R41	1	82 kΩ	SMD 1206
R52, R53, R65, R66, R67	5	100 kΩ	SMD 1206
R56, R70, R71, R72	4	10 MΩ	SMD 1206
U1	1	L6562D	STMicroelectronics, transistor mode PFC controller

Table 4. STEVAL-ILH002V1 bill of material (continued)

Reference	Qty	Value/part number	Description
U4	1	L6571AD	STMicroelectronics, high-voltage half-bridge driver with programmable oscillator frequency
U8	1	LM139D	STMicroelectronics, low-power quad voltage comparator
R73	1	Wire jump on pin 1 and 2	

Appendix C L6562D transistor mode PFC controller

Figure 26. L6562D block diagram



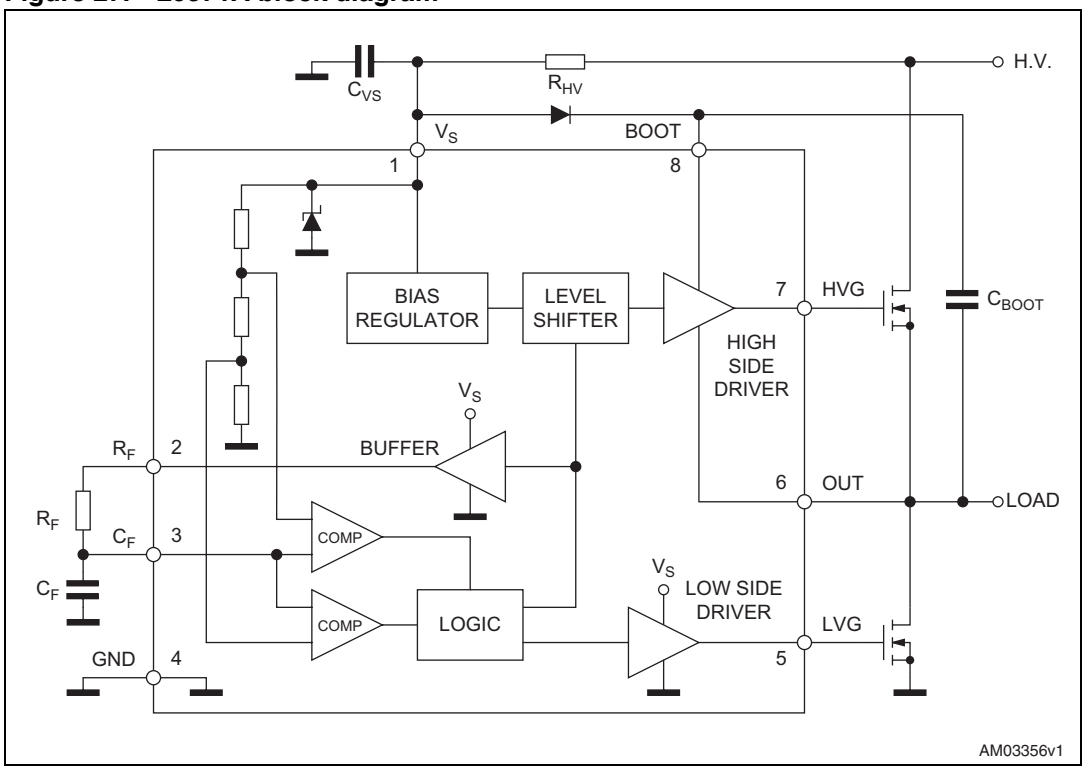
The L6562D is a current-mode PFC controller operating in transition mode TM, using BCD technology. The highly linear multiplier includes a special circuit, able to reduce AC input current distortion, that allows wide-range-mains operation with an extremely low THD, even over a large load range. The output voltage is controlled by means of a voltage-mode error amplifier and a precise (1% at T_J = 25 °C) internal voltage reference.

The main characteristics of this driver are:

- Ultra-low (≤ 70 µA) startup current
- Low (≤ 4 mA) quiescent current
- Extended IC supply voltage range
- On-chip filter on current sense
- Disable function
- 1% (at T_J = 25 °C) internal reference voltage
- -600/+800 mA totem pole gate driver with UVLO pull-down and voltage clamp
- DIP-8/SO-8 packages ECOPACK®.

Appendix D L6571A high-voltage half-bridge driver with oscillator

Figure 27. L6571A block diagram



The L6571A is a high half-bridge driver with built-in oscillator. The frequency of the oscillator can be programmed using an external resistor and capacitor. The internal circuitry of the device allows it to be driven also by an external logic signal. The output drivers are designed to drive an external n-channel power MOSFET and IGBT. The internal logic assures a deadtime to avoid cross-conduction of the power device.

The main characteristics of this driver are:

- High-voltage rail up to 600 V
- BCD offline technology
- 15.6 V Zener clamp on Vs
- Driver current capability:
  - sink current = 270 mA
  - source current = 170 mA
- Very low startup current = 150 µA
- Undervoltage lockout with hysteresis
- Programmable oscillator frequency
- Deadtime 1.25 µs (L6571A) or 0.72 µs (L6571B)
- dv/dt immunity up ±50 V/ns
- ESD protection

Appendix E LM139 low-power quad voltage comparators

Figure 28. LM139 pin connection

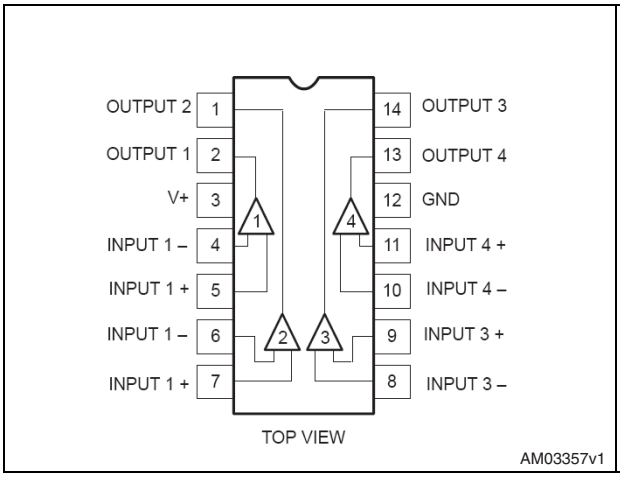
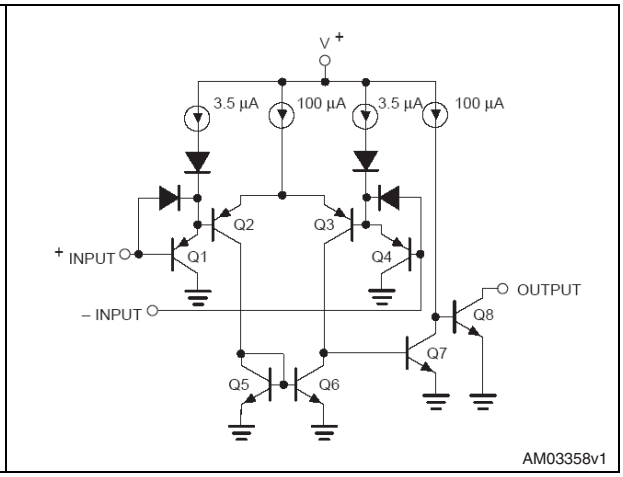


Figure 29. LM139 schematic diagram



The LM139 consists of four independent precision voltage comparators with an offset voltage specification as low as 2 mV max. for LM339A, LM239A and LM139A. All these comparators were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible. These comparators also have a unique characteristic in that the input common mode voltage range includes ground even though operated from a single power supply voltage.

The main characteristics are:

- Wide single supply voltage range or dual supplies for all devices:
  - +2 V to +36 V or ±1 V to ±18 V
- Very low supply current(1.1 mA) independent of supply voltage (1.4 mW/comparator at +5 V)
- Low input bias current: 25 nA typ.
- Low input offset voltage: ±1 mV typ.
- Input common mode voltage range includes ground
- Low output saturation voltage: 250 mV typ. (Io = 4 mA)
- Differential input voltage range equal to the supply voltage
- TTL, DTL, ECL, MOS, CMOS compatible outputs.

Appendix F PFC inductor 1.2 mH, 0.34 A

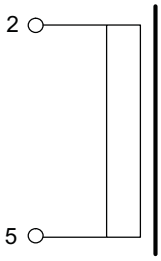
Figure 30. PFC inductor 1.2 mH, 0.34 A

STP 04	Product Technical Specification	Code : 1851.0001
Product: PFC Inductor 1.2mH 0.34A		
Customer: STMicroelectronics		*Customer Code:* L6
Date : 03/03/09 *Revision:* 0		Page 1 di 1

TIPICAL APPLICATION

INDUCTOR FOR BUCK, BOOST AND BUCK-BOOST DC/DC CONVERTER, AVAILABLE ALSO IN HALF-BRIDGE, PUSH-PULL AND FULL-BRIDGE APPLICATIONS

SCHEMATIC

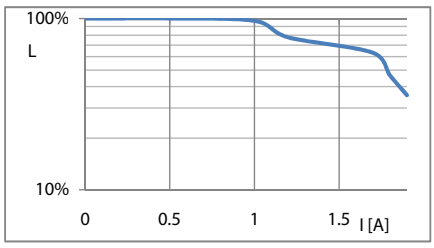


WINDINGS CONSTRUCTION			
START	END	COILS	WIRE DIAMETER
2	5	150	∅0.28 G2

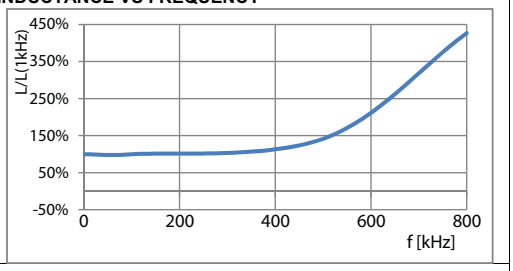
TECHNICAL DATA

INDUCTANCE *(MEASURE 1KHZ, TA 20°C)*	1.2 mH ±15%
RESISTANCE(*MEASURE DC, TA 20°C)*	922 mΩ MAX
WORKING VOLTAGE *(F 70KHZ, IR 0.34A, TA 20°C)*	600 V MAX
OPERATING CURRENT *(MEASURE DC , TA 20°C)*	340mA MAX
SATURATION CURRENT *(MEASURE DC, L ≥ 50%NOM, TA 20°C)*	1.9A MAX
RESONANCE FREQUENCY *(TA 20°C)*	860KHZ NOM
OPERATING TEMPERATURE RANGE *(IR A MAX)*	-10°C÷+45°C
MAXIMUM DIMENSIONS	21x14x22mm
WEIGHT	8g CIRCA

INDUCTANCE VS CURRENT

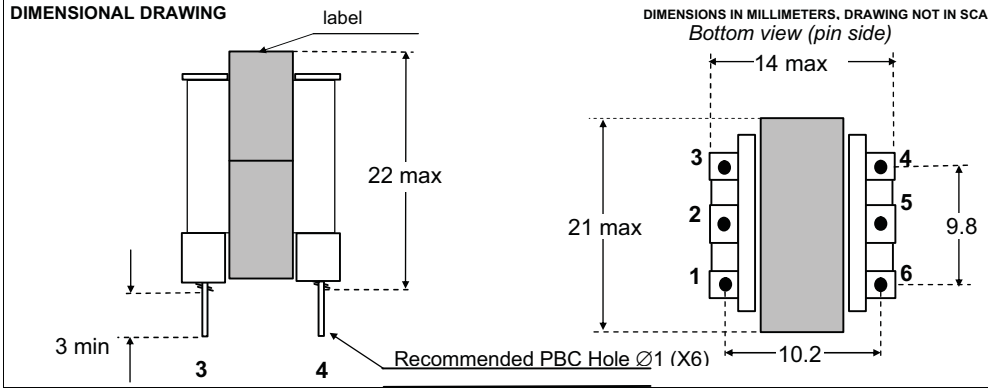


INDUCTANCE VS FREQUENCY



DIMENSIONAL DRAWING

DIMENSIONS IN MILLIMETERS, DRAWING NOT IN SCALE



MOR&D0014-00 Rev.00 02/09/08

MAGNETICA

AM03361v1

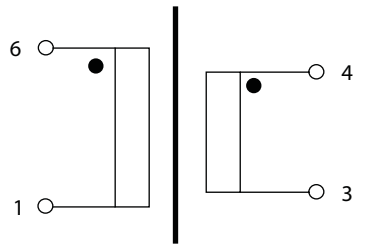
Appendix G Transformer ignition

Figure 31. Transformer ignition

STP 23	Product Technical Specification	Code : 1814.0001
Product : Transformer Ignitor 3.5mH		
Customer: STMicroelectronics		Customer code:
Date : 02/03/09	Revision : 0	Page 1 di 2

TYPICAL APPLICATION
HID IGNITION TRANSFORMER FOR 35W HID LAMP

SCHEMATIC



WINDINGS CONSTRUCTION			
START	END	COILS	WIRE DIAMETER
6	1	210	∅ 0.28 G2
		3	Tape
4	3	42	∅ 0.28 G2
		1	Tape

TECHNICAL DATA

INDUCTANCE
(MEASURE 1KHZ, TA 20°C)
PIN 6-1 3.5 mH ± 15%
PIN 4-3 156 uH ± 15%

RESISTANCE
(MEASURE D .C, TA 20°C)
PIN 6-1 2.3 Ω MAX
PIN 4-3 300 mΩ MAX

TRANSFORMER RATIO
(MEASURE 10KHZ, TA 20°C)
PIN ⇔ 6-1 ⇔ 4-3 5 ± 5%

OPERATING CURRENT
(TERMINALI 6-1, F 100÷200H Z, TA 20°C)
STADY STATE 420 mA_P MAX
START UP 3 A_P MAX

OPERATING TEMPERATURE RANGE -10°C ÷+45°C

PRIMARY TO SECONDARY INSULATION 2500 V_{DC}
(F 50H Z,DURATION TEST <1µSEC , TA 20°C)

MAXIMUM DIMENSIONS 21 X15 X21 mm

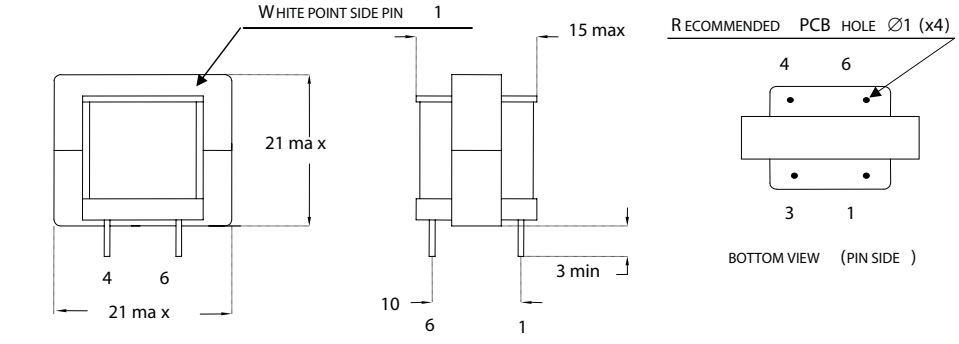
WEIGHT 14 g CIRCA

PIN DESCRIPTION

PIN (*)	FUNCTION	PIN (*)	FUNCTION
1	END SECONDARY	4	START PRIMARY
2	NOT PRESENT	5	NOT PRESENT
3	END PRIMARY	6	START SECONDARY

(*)P IN WITH THE SAME SUBSCRIPT MU ST BE CONNECTED TOGETHER ON PCB

DIMENSIONAL DRAWING



DIMENSIONS IN MILLIMETERS , DRAWING NOT IN SCALE

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Appendix H Inductor 680 µH, 0.3 A

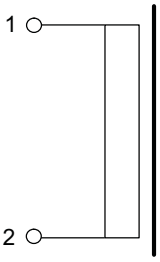
Figure 32. Inductor 680 µH, 0.3 A

STP 04	Product Technical Specification	Code : 1551.0006
Product: Inductor 680uH 0.3A		
Customer: **STMicroelectronics**		*Customer Code:*
Date :02/03/09 *Revision:* 0		Page 1 di 1

TIPICAL APPLICATION

INDUCTOR FOR BUCK, BOOST AND BUCK-BOOST DC/DC CONVERTER, AVAILABLE ALSO IN HALF-BRIDGE, PUSH-PULL AND FULL-BRIDGE APPLICATIONS

SCHEMATIC

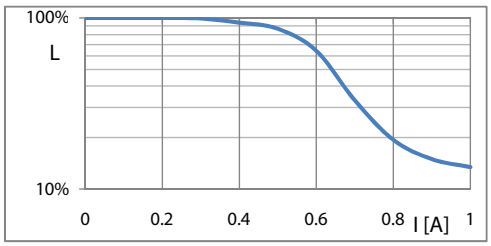


WINDINGS CONSTRUCTION			
START	END	COILS	WIRE DIAMETER
1	2	137.5	∅0.224 G1

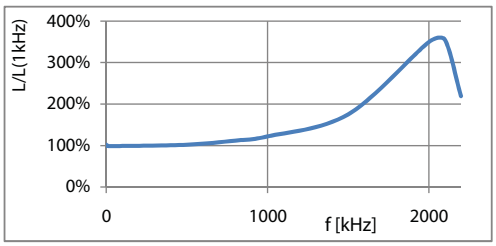
TECHNICAL DATA

INDUCTANCE *(MEASURE 1KHZ, TA 20°C)*	680 uH ±30%
RESISTANCE *(MEASURE DC, TA 20°C)*	1.15 Ω MAX
OPERATING CURRENT *(MEASURE DC , TA 20°C)*	300 m A MAX
SATURATION CURRENT *(MEASURE DC, L ≥ 50%NOM, TA 20°C)*	0.65 A MAX
RESONANCE FREQUENCY *(TA 20°C)*	2.1 MHZ NOM
OPERATING TEMPERATURE RANGE *(IR 0.3A MAX)*	-10°C÷+45°C
MAXIMUM DIMENSIONS	∅8x12 mm
WEIGHT	2 g CIRCA

INDUCTANCE VS CURRENT

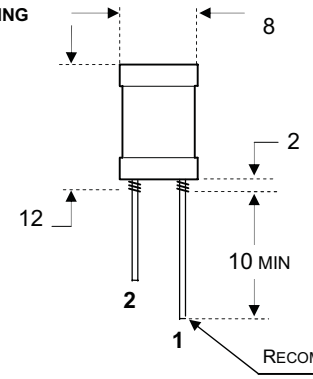


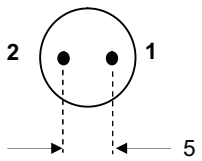
INDUCTANCE VS FREQUENCY



DIMENSIONAL DRAWING

DIMENSIONS IN MILLIMETERS, DRAWING NOT IN SCALE





BOTTOM VIEW (PIN SIDE)

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Appendix I Switch mode transformer 35 W, 70 kHz, 2.3 mH

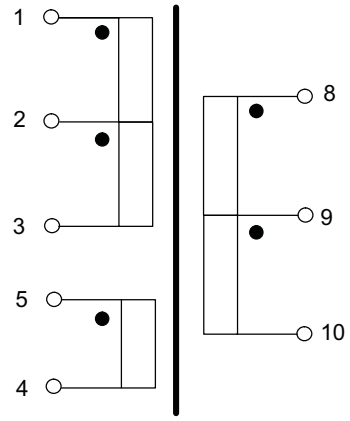
Figure 33. Switch mode transformer 35 W, 70 kHz, 2.3 mH

STP 21	Product Technical Specification	Code: 1318.0006
Product: Switch Mode Transformer 35W 70kHz 2.3mH		
Customer: **STMicroelectronics**		Customer code:
Date : 02/03/09	Revision: 0	Page 1 of 2

TYPICAL APPLICATION

TRANSFORMER FOR FLYBACK POWER SUPPLIES IN APPLICATIONS WITH 35W HID BALLAST

CIRCUIT DIAGRAM



WINDINGS CONSTRUCTION			
START	END	COILS	WIRE DIAMETER
1	2	54	∅ 0.25 G2
		1	Tape
8	9	45	∅ 0.28 G2
		1	Tape
2	3	54	∅ 0.25 G2
		1	Tape
9	10	45	∅ 0.28 G2
		1	Tape
5	4	16	∅ 0.25 G2
		1	Tape

TECHNICAL DATA

INDUCTANCE
(*MEASURE 1KHZ, TA 20°C*)

PIN 1 - 3	2.3 mH ± 15%
PIN 8 -10	1.5 mH ± 15%
PIN 5 - 4	49 uH ± 15%

RESISTANCE
(*MEASURE D.C, TA 20°C*)

PIN 1 - 3	1.8 Ω MAX
PIN 8 - 10	1.25 Ω MAX
PIN 5 - 4	324 mΩ MAX

TRANSFORMER RATIO
(*MEASURE 10KHZ, TA 20°C*)

PIN 1-3 ⇔ 8-10	1.2 ± 5%
PIN 1-3 ⇔ 5-4	6.75 ± 5%

LEAKAGE INDUCTANCE 0.41% NOM
(MEASURE 1-3 AND 4-5-8-9-10 IN S.C, F 10KHZ, TA 20°C)

SATURATION CURRENT 0.82 A_P MAX
(MEASURE 1-3, B_{SAT} 0.3T, TA 20°C)

OPERATING CURRENT 0.74 A_P MAX
(MEASURE 1-3, P_{MAX} 35W ,F 70KHZ, TA 20°C)

OPERATING FREQUENCY 70 KHZ NOM
(P_{MAX} 35W , TA 20°C)

OPERATING TEMPERATURE RANGE -10°C÷+45°C
(P_{MAX} 35W)

PRIMARY TO SECONDARY INSULATION 1000 V
(F 50HZ,DURATION TEST 2", TA 20°C)

MAXIMUM DIMENSIONS 26x27x13 mm

WEIGHT 22 g ABOUT

PIN DESCRIPTION

PIN(*)	*FUNCTION*	*PIN(*)*	*FUNCTION*
1	PRIMARY+ V_B	6	NOT PRESENT
2	PRIMARY CENTER TAP	7	NOT CONNECTED
3	PRIMARY DRAIN	8	SECONDARY GROUND
4	AUXILIARY	9	SECONDARY CENTER TAP
5	AUXILIARY GROUND	10	SECONDARY

(*)PIN WITH THE SAME SUBSCRIPT MUST BE CONNECTED TOGETHER ON PCB

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Revision history

Table 5. Document revision history

Date	Revision	Changes
21-Sep-2009	1	Initial release

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